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HANDBOOK OF ASTRONOMY.

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PORTION OF THE LUNAR SURFACE IN THE
OF THE CRATER TYCHO.

[This illustration is a photo-wood-engraving from a model by Mr. Na
this work by Messrs. Bradbury, Evans,

HANDBOOK

OF

ASTRONOMY.

BY

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WITH ILLUSTRATIONS ON STONE AND WOOD.

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PREFACE.

It has been the purpose of the Author in the composition of this work to lay before the reader, in a clear and concise manner, the principles of astronomy, developed and demonstrated in ordinary and popular language, capable of being understood by those who may be possessed of an average amount of general knowledge. Perhaps at no time more than the present, when by the influence of the Oxford and Cambridge middle-class examinations, the education of the youth of the present generation is receiving unusual attention, has the want been more felt of elementary works on the different branches of scientific knowledge, possessing sound and reliable information expressed in language attractive to the reader. The study of such works would prepare him for more advanced treatises on the separate sciences.

In the present edition of this work the Editor has endeavoured so to arrange the various sections of the science, as to exhibit to the inquiring reader the various movements and physical peculiarities of the different members of the solar system, without embarrassing his mind with mathematical symbols; for though symbolical explanations may seem to the advanced student to be a necessary adjunct for the proper elucidation of the different problems, yet it not unfrequently happens that the reader, with less mathematical proficiency, would altogether fail in the study of this science, were it not for the assistance afforded by popular and elementary works written in a lan-

guage comprehended by all. To the student of the higher or mathematical branches of astronomy, this work, however, will also be found interesting and instructive, as he will find information of the most valuable kind in it, for much of which he may look in vain in works of higher pretensions.

It is well known that students may pass through their educational course without acquiring even a general knowledge of geometry and algebra. To all such persons, mathematical treatises on astronomy must be sealed books. Such students, notwithstanding their inability to understand works of that kind, may acquire a considerable acquaintance with this science, by consulting the various divisions of a work like the present, which though free from the usual symbols of mathematical explanations, is founded on reasoning sufficiently satisfactory and conclusive.

The rapid succession of discoveries by which astronomical knowledge has been extended during the last twenty-two years has rendered elementary works on astronomy, published previously to 1845, to a certain extent, obsolete; while the increasing taste for the cultivation of the science, and the multiplication of private observatories and amateur observers, have created a demand for treatises, which shall comprise not only explanations of the movements of the earth and the other bodies of the solar system, but also illustrations of the physical appearances of the different planets, the information on which can only otherwise be obtained by reference to the *Transactions* of the various scientific societies of different countries, formed for the encouragement of astronomy and the other physical sciences.

In illustration of this, we have only to refer the reader to the results which have been obtained from the researches of original inquirers, and from the labours of observers, which have been carefully reviewed, and from which large selections have been made, and presented to the reader in a popular and instructive form. In cases where the subject required graphic

illustrations for its better elucidation, and when such representations could be obtained from original and authentic sources, they have been unsparingly supplied.

As examples of this we may refer among the planetary objects to the beautiful delineations of the Moon and Mars by MM. Beer and Mädler; those of Jupiter by Sir John Herschel and M. Mädler; and those of Saturn by MM. Dawes and Schmidt: among cometary objects, to the magnificent drawings of Encke's comet by M. Struve, and to those of Halley's comet by MM. Struve, Maclear, and Smyth; and among stellar objects, to the splendid selection of stellar clusters and nebulæ, which are reproduced from the originals of the Earl of Rosse and Sir John Herschel. We also draw attention to the remarkable drawings of solar spots by MM. Capocci and Pastorff, delineations of which will be found in this volume.

To have entered into the details of the business of an observatory, beyond those explanations which are necessary and sufficient to give the reader a general notion of the processes by which the principal astronomical data are obtained, would not have been compatible with the popular character and limited dimensions of such a treatise as the present.

It has, nevertheless, been thought advisable to insert in the body of the work, short notices of the most remarkable astronomical instruments, celebrated as examples of beauty of construction combined with unusual stability. Most of these instruments, especially the great equatorial, recently erected at the Royal Observatory, Greenwich, are magnificent models of engineering skill, and reflect honour on all who may have assisted in their construction. Well executed drawings of most of these astronomical instruments will be found inserted in the chapter devoted to this subject, the originals for some of which have been either supplied by or made under the superintendence of the eminent astronomers under whose direction the instruments are placed.

The progress of astronomical discovery has in no section of the science shown greater activity than in that treating of the numerous planets composing the solar system, to which have been added since the year 1845, no fewer than eighty-seven of those minute bodies whose orbits, without exception, are included between those of Mars and Jupiter. The reader will find in the chapter under the name of "The Planetoids," information regarding the discovery of each of these planets, together with other matter relating to them, the planets appearing in the order of their discovery. The Editor is not aware of any work containing the same amount of information on all the planetoids, the existence of which was known at the date of passing the chapter through the press.

In the body of the work, chiefly on account of the limited extent of the volume, subjects which require some amount of mathematical elucidation are necessarily omitted. Those of our readers who wish to enter upon the study of the theoretical branches of the science, such as the theory of planetary perturbations, or the lunar theory, &c., should select those works which are specially prepared for students in the universities, on each of these important subjects. Our limits will not allow us to include them without sacrificing other instructive matter which agrees more with the objects and intentions of this work. The reader will, however, find inserted in the concluding chapter, further explanations on a few questions which in an earlier portion of the work have been partially treated on in the text.

The tabular numbers representing the principal elements of the various members composing the solar system, have been selected from the most recent authorities. Those tables which are the result of computation, have all undergone rearrangement and recalculation, and the separate numbers will, i is hoped, be consequently received with some degree confidence.

[redacted]

NOTE TO THE THIRD EDITION.

In preparing this Edition, it has not been considered necessary to make any serious alteration in the material or arrangement adopted in the Second Edition. We have, however, given the work a careful revision. In conformity with the opinion of our leading astronomers, the mean equatorial horizontal parallax of the sun has now been authoritatively increased from $8''\cdot5776$ to $8''\cdot94$. The modification of this standard element in astronomy has created the necessity of our making important numerical corrections throughout the volume corresponding to the amount of the increase. We have also added, as an Appendix, brief notes, or abstracts, of a few of the principal recent astronomical researches; and in Chapter XV. notices of the discovery of thirty-three additional minor planets have been inserted.

E. D.

Greenwich: *February* 7, 1867.

[redacted]

NOTE.

Reference is frequently made in the text of this volume to the paragraphs contained in the "Handbooks of Natural Philosophy," by Dr. Lardner, which bear on the same subject as that under discussion. The name of the work corresponding to each letter of reference is therefore inserted below as an assistance to the reader, who will find in these separate treatises several explanations of subjects which tend to elucidate more clearly those given in this volume.

The volume on	MECHANICS	is referred to by the letter		M.
"	HYDROSTATICS PNEUMATICS HEAT	"	"	H. or P.
"	OPTICS	"	"	O.

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from the Greek words ἀστηρ (aster), A STAR (under which all the heavenly bodies were included), and νομος (nomos), A LAW—the science which expounds the LAWS which govern the motions of the STARS.

4. **It treats of inaccessible objects.**—It is evident, therefore, that astronomy is distinguished from all other divisions of natural science by this peculiarity, that the bodies which are the subjects of observation and inquiry are all of them INACCESSIBLE. Even the earth itself, which the astronomer regards as a celestial object—an ἀστηρ,—is to him, in a certain sense, even more inaccessible than the others; for the very fact of his place of observation being confined strictly to its surface, an insignificant part of which alone can be observed by him at any one moment, renders it impossible for him to examine, by direct observation, the earth AS A WHOLE,—the only way in which he desires to consider it,—and obliges him to resort to a variety of indirect expedients to acquire that knowledge of its dimensions, form, and motions which, with regard to other and more distant objects, results from direct and immediate observation. This circumstance of having to deal exclusively with inaccessible objects has obliged the astronomer to invent peculiar modes of reasoning, and peculiar instruments of observation, adapted to the solution of such problems, and to the discovery of the necessary data.

5. **Direction and bearing of visible objects.**—The eye estimates only the direction or relative bearings of objects within the range of vision, but supplies no direct means of determining their distances from each other, or from the eye itself.

The absolute direction of a visible object is that of a straight line drawn from the eye to the object.

The relative direction or bearing of an object is determined by the angle formed by the absolute direction with some other fixed or known direction, such as that of a line drawn to the north, south, east, or west.

6. **They supply the means of ascertaining the distances and positions of inaccessible objects.**—By comparing the relative bearings of inaccessible objects, taken from two or more accessible points whose distance from each other is known, or can be ascertained by actual measurement, the distances of such inaccessible objects from the accessible objects, from the observer, and from each other, may be determined by computation. Such distances being once known, become the data by which the mutual distances of other inaccessible objects from the former, and from each other, may be in like manner computed; so that, by starting in this manner from two objects whose mutual distance can be actually measured, we may proceed, by a chain of computations, to

determine the relative distances and positions of all other objects, however inaccessible, that fall within the range of vision.

7. **Angular magnitude—its importance.**—It will be apparent, therefore, that ANGULAR MAGNITUDE plays a most prominent part in astronomical investigations, and it is, before all, necessary that the student should be rendered familiar with it.

8. **Division of the circle—its nomenclature.**—A circle is divided into four equal arcs, called quadrants, by two diameters AA′ and BB′ intersecting at right angles at the centre C, *fig.* 1.

Fig. 1.

The circumference being supposed to be divided into 360 equal parts, each of which is called a DEGREE, a quadrant will consist of 90 degrees.

Angles are subdivided in the same manner as the arcs which measure them, and accordingly a right angle, such as A C B, being divided into 90 equal angles, each of these is a DEGREE.

If an angle or arc of one degree be divided into 60 equal parts, each of these is called a MINUTE.

If an angle or arc of one minute be divided into 60 equal parts, each such part is called a second.

Angles less than a second are usually expressed in decimal parts of a second.

Degrees, minutes, and seconds of SPACE are usually expressed by the signs °, ′, ″; thus 23° 30′ 40″·9 means an angle or arc which measures 23 degrees, 30 minutes, 40 seconds, and 9 tenths of a second.

The letters *m* and *s* are generally used to express minutes and seconds of TIME. Thus, $23^h\ 30^m\ 40^s{\cdot}9$, expresses an interval of time consisting of 23 hours, 30 minutes, 40 seconds, and 9 tenths of a second. This symbolical distinction in representing time and space is found not only a practical convenience in computations where both must necessarily appear, but it is also a means of preventing many errors which may easily occur, when one set of symbols is used in both cases.

9. **Methods of ascertaining the direction of a visible and distant object.**—It might appear an easy matter to observe the exact direction of any point placed within the range of vision, since that direction must be that of a straight line passing directly from the eye of the observer to the point to be observed. If the eye were supplied with the appendages necessary to record and measure the directions of visible objects, this would be true, and the organ of sight would be in fact a philosophical instrument.

The eye is, however, adapted to other and different uses, and constructed to play a different part in the animal economy; and invention has been stimulated to supply expedients, by means of which the exact directions of visible distant points can be ascertained, observed, and compared one with another, so as to supply the various data necessary in the classes of problems connected with astronomy, some of which we shall have occasion hereafter to advert to.

10. **Use of sights.**—The most simple expedient by which the visual direction of a distant point can be determined is by SIGHTS, which are small holes or narrow slits made in two thin opaque plates placed at right angles, or nearly so, to the line of vision, and so arranged, that when the eye is placed behind the posterior opening the object of observation shall be visible through the anterior opening. Every one is rendered familiar with this expedient by its application to fire-arms as a method of "taking aim."

This contrivance is, however, too rude and susceptible of error within too wide limits, to be available for astronomical purposes, though occasionally it is used in large instruments as an assistance in setting for bright objects.

11. **Application of the telescope to indicate the visual direction of micrometric wires.**—The telescope (O. 501) supplies means of determining the direction of the visual ray with all the necessary precision.

If T T′, *fig.* 2, represent the tube of a telescope, T the extremity in which the object-glass is fixed, and T′ the end where the images

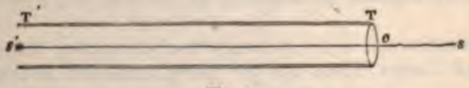


Fig. 2.

of distant objects to which the tube is directed are formed, the visual direction of any object will be that of the line *s′ c* drawn from the image of such object formed in the *field of view* of the telescope to the centre *c* of the object-glass, for if this line be continued it will pass through the object *s*.

But since the field of view of the telescope is a circular space of definite extent, within which many objects in different directions may at the same time be visible, some expedient is necessary by which one or more fixed points in it may be permanently marked, or by which the entire field may be spaced out as a map, by the lines of latitude and longitude.

This is accomplished by a system of fibres, or wires (M. 38) so thin that even when magnified they will appear like hairs. In

instruments of great precision, the web of a peculiar kind of spider is used for this purpose. These wires are extended in a frame fixed within the eye-piece of the telescope, so that they appear when seen through the eye-glass like fine lines drawn across the field of view. They are differently arranged, according to the sort of observation to which the instrument is to be applied.

12. **Line of collimation.**—In some cases two wires intersect at right angles at the centre of the field of view, dividing it into quadrants, as represented in *fig.* 1. The wires are so adjusted that their point of intersection C coincides with the axis of the telescopic tube; and when the instrument is so adjusted that the point of observation, a star for example, is seen precisely upon the intersection C of the wires, the line of direction, or visual ray of that star, will be the line *s′ c*, *fig.* 2, joining the intersection C, *fig.* 1, of the wires with the centre *c*, *fig.* 2 of the object-glass.

The line *s′ c*, *fig.* 2, is technically called the *line of collimation.*

13. **Application of the telescope to a graduated instrument.**—The telescope thus prepared is attached to a graduated instrument by which angular magnitudes can be observed and measured. Such instruments vary infinitely in form, magnitude, and mode of mounting and adjustment, according to the purposes to which they are applied, and to the degree of precision necessary in the observations to be made with them. To explain and illustrate the general principles on which they are constructed we shall take the example of one, which consists of a complete circle graduated in the usual manner, being the most common form of instrument used in astronomy for the measurement of angular distances.

Such an apparatus is represented in *fig.* 3. The circle A B C D, on which the divisions of the graduation are accurately engraved, is

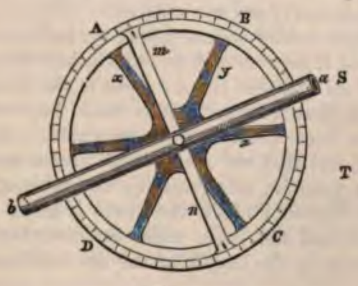


Fig. 3.

connected with its centre by a series of spokes x y z. At its centre is a circular hole, in which an axle is inserted so as to turn smoothly

in it, and while it turns to be always concentric with the circle A B C D. To this axle the telescope *a b* is attached in such a manner that the imaginary line *s' c*, *fig.* 2, which joins the intersection of the wires, *fig.* 1, with the centre of the object-glass, shall be parallel to the plane of the circle, and in a plane passing through its centre and at right angles to it.

At right angles to the axis of the telescope are two arms, *m n*, which form one piece with the tube, so that when the tube is turned with the axis to which it is attached, the arms *m n* shall turn also, always preserving their direction at right angles to the tube. Marks or indices are engraved upon the extremities *m* and *n* of the arms which point to the divisions upon the LIMB (as the divided arc is called).

A clamp is provided on the instrument, by which the telescope, being brought to any desired position, can be fixed immovably in that position, while the observer examines the divisions upon the limb to which the indices *m* and *n* are directed.

Now let us suppose that the visual angle under the directions of two distant objects within the range of vision is required to be measured. The circle being brought into the plane of the objects, and fixed in it, the telescope is moved upon its axis until it is directed to one of the objects, so that its image shall coincide exactly with the intersection of the wires. The telescope is then clamped, and the observer examines the divisions of the divided limb, to which one of the indices, *m* for example, is directed. This process is called "reading off." The clamp being disengaged, the telescope is then in like manner directed to the other object, and being clamped as before, the position of the index is again "read off." The difference between the numbers which indicate the position of the same index in both cases, will evidently be the visual angle under the directions of the two objects.

As a means of further accuracy, both the indices *m* and *n* may be "read off," and if the results differ, which they always will slightly, owing to various causes of error, a mean of the two may be taken.

It is evident that the same results would be obtained if, instead of making the telescope move upon the circle, it were immovably attached to it, and that the circle itself turned upon its centre, as a wheel does upon its axle, carrying the telescope with it. In this case the divided limb of the circle is made to move before a fixed index, and the angle under the directions of the objects will be measured by the length of the arc which passes before the index.

Such a combination is represented in section in *fig.* 4, where T is the telescope, *p* the pieces by which it is attached to the circle A B seen edgewise, the axis of which D works in a solid block of metal.

The fixed index F is directed to the graduated limb which moves before it.

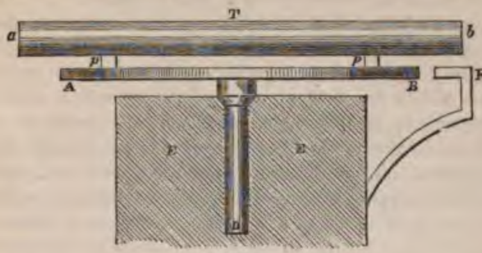


Fig. 4.

This is the most frequent method of mounting instruments used in astronomy for angular measurement.

14. **Expedients for measuring the fraction of a division.**— It will happen in general that the index will be directed, not to any exact division, but to some point intermediate between two divisions of the limb. In that case expedients are provided by which the distance between the index and the last division which it has passed, may be ascertained with an extraordinary degree of precision.

15. **By a vernier.**—This may be accomplished by means of a supplemental scale called a VERNIER. (P 229.)

16. **By a compound microscope, and micrometric screw.**—The same object may, however, be attained with far greater accuracy by means of a compound microscope mounted as represented in *fig.* 5, so that the observer looks at the index through it. A system of cross wires is placed in the field of view of the microscope, and the whole may be so adjusted by the action of a fine screw, that the index shall coincide precisely with the intersection of the wires. The screw is then turned until the intersection of the cross is brought to coincide with the previous division of the limb; and the number of turns and fraction of a turn of the screw will give the fraction of a degree between the index and the previous division of the limb.

Fig. 5.

It is necessary, however, to ascertain previously the value of a complete revolution of the screw. This is easily done by placing the cross-wires which are carried by the micrometric screw, on consecutive divisions of the limb. Dividing, then, the value in arc be-

tween two divisions, which is always known, by the number of turns and fraction of a turn, the arc which corresponds to one complete revolution of the micrometric screw, will be found.

17. **Observation and measurement of minute angles.**— When the points between which the angular distance required to be ascertained are so close together as to be seen at one and the same time within the field of view of the telescope, a method of measurement is applicable, which admits of even greater relative accuracy than do the methods of observing large angular distances. This arises from the fact that the distance between such points may be determined by various forms of micrometric instruments, in which fine wires, or lines of spider's web, are moved in a direction perpendicular to their length, so as to pass successively through the points whose distance is to be observed.

18. **The parallel wire micrometer.**— One of the forms of micrometric apparatus used for this purpose is represented in transverse section in *fig.* 6. This, which is called the PARALLEL WIRE

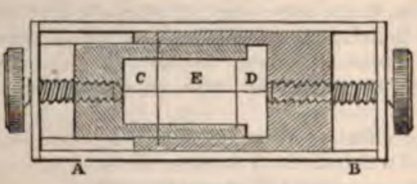


Fig. 6.

MICROMETER, consists of two sliding frames, across which the parallel wires or threads C D are stretched. These frames are both moved in a direction perpendicular to that of the wires by screws, constructed with very fine threads, and called from their use MICROMETER-SCREWS. This frame is placed in the focus of the object-glass of the telescope, so that the eye viewing the objects under observation sees also distinctly the parallel and movable wires. These wires are moved by the screws until they pass through the points, whose distance asunder is to be measured. This being accomplished, one of them is moved until it coincides with the other, and the number of turns and parts of a turn of the screw necessary to produce this motion, gives the angular distance between the points under observation.

In this, as in the case explained in (16) it is necessary that the angle corresponding to one complete revolution of the micrometer-screw be previously ascertained; and this is done by a process precisely similar to that explained in the former case. An object

of known angular magnitude, as, for example, a foot rule at the distance of a hundred yards, is observed, and the number of turns necessary to carry the wire from end to end of its image is ascertained. The angle such a rule subtends at that distance being divided by the number of turns and parts of a turn, the quotient is the angle corresponding to one complete revolution of the screw.

19. **Measurement of the apparent diameter of an object.**—When an object is not too great to be included in the field of view of the telescope, its apparent diameter can be measured by such an apparatus. To accomplish this, these screws are turned until the wires C and D, *fig.* 6, are made to touch opposite sides of the disk of the object. One of the screws is then turned until the wires coincide, and the number of turns and parts of a turn gives the apparent magnitude.

20. **The double image micrometer.**—The method in general practice in large observatories for the measurement of apparent diameters of planets and angular distances of binary stars, is by means of the DOUBLE IMAGE MICROMETER. This apparatus consists of a four-glass eye-piece, in which the lenses are so arranged, that the axis of the pencil of rays from each point of an observed object, passes through the centre of the lens which is next to the object-glass. One half of this lens is fixed, the other is moved by a micrometer-screw with a graduated head. The instrument is furnished with a small graduated circle, by which the angles of position of objects may be measured.

In the field of view two images are seen, one of them being fixed, the other movable by the aid of the micrometer-screw. The diameter of an object is therefore found by placing one edge of the movable object in coincidence with the edge of the fixed object, and then reading the divisions on the micrometer-head. The screw is then turned until the movable image is on the opposite side of the fixed image when they are placed in coincidence as before. The difference of the two micrometer readings is twice the diameter of the object in terms of revolutions of the micrometer-screw. The value of one revolution being known, the angular measurement is easily determined.

CHAPTER II.

ASTRONOMICAL INSTRUMENTS, AND THEIR MODE OF USE.

21. **Knowledge of the instruments of observation necessary.**— Before proceeding to explain the form and density of the earth, or the general aspect of the firmament, and fixed lines and points upon it, by which the relative position and motions of celestial objects are defined, it will be necessary to explain the principal instruments with which an observatory is furnished, and to show the manner in which they are applied, so as to obtain those accurate data which supply the basis of those calculations from which has resulted our knowledge of the great laws of the universe. We shall therefore here explain the form and use of such of the instruments of an observatory as are indispensably necessary for the observations by which such data are supplied.

All astronomical observation is limited either to ascertain the magnitudes, forms, and appearance of celestial objects, or to determine the places they occupy at any given moment on the firmament.

To attain the former object, telescopes are constructed with the greatest practicable magnifying and illuminating powers, and so mounted as to enable the observer with all the requisite facility to present them to those parts of the heavens in which the objects of his observation are placed.

To attain the latter, it is necessary to provide an apparatus by which the direction of the visual line of the object of observation relatively to some fixed line and some fixed plane can be ascertained. The visual line being the straight line drawn from the eye of the observer to the object, at the moment of the observation, and having, therefore, no material tangible or permanent existence, by which it can be submitted to measurement, it is necessary to contrive some material line with which the visual line shall coincide. The telescope supplies an easy and exact means of accomplishing this. When it is directed so that the object or its centre, if it have a disk, is seen upon the intersection of the middle wires in the eye-piece, the visual direction of the object is the line drawn from the centre of the object-glass of the telescope to the intersection of the middle wires.

Now the telescope being attached to a graduated circle is so

placed, that the line joining the centre of the object-glass with the intersection of the wires is parallel to a diameter of the circle. This diameter will therefore be the direction of the visual line. If the circle thus arranged be so mounted that a line drawn from the observer to the fixed point of reference, whatever that point be, shall be parallel also to a diameter of the circle, and if the circle be so mounted that, however its position may otherwise be changed, one of its diameters shall always pass through the fixed point of reference, the angular distance of the object of observation from the fixed point of reference will always be equal to the angle formed by the two diameters of the circle, one of which is parallel to the line joining the centre of the object-glass, with the intersection of the wires at the moment of the observation, and the other parallel to the line drawn from the observer to the fixed point of reference.

But this is not yet enough to determine in a definite manner the position of the object on the heavens. A great many different objects may have the same angular distance from the fixed point of reference. If a plane be imagined to pass at right angles to a line drawn from the observer to the fixed point of reference, it will intersect the celestial sphere in a certain circle, every point of which will obviously be at the same angular distance from the point of reference. To render the position of the object of observation determinate, it is therefore necessary to know the position of the plane of the graduated circle, with relation to a circle whose plane is at right angles to that diameter of the celestial sphere which passes through the fixed point of reference.

The plane of the graduated circle may be fixed or movable. If fixed, its position with relation to the fixed point of reference is ascertained once for all; after which, the position of the object of observation will be determined merely by its angular distance from the point of reference. If movable, it is necessary to provide another graduated circle, the plane of which is perpendicular to the first, and upon which some fixed direction is marked. The position of the plane of the movable circle, which carries the telescope, with relation to this latter fixed direction, is then ascertained by the arc of the second graduated circle, which is included between the movable circle and such fixed direction.

All instruments of observation for determining the position of objects on the celestial sphere are constructed and mounted on one or other of these principles; and they differ one from another in respect to the point adopted as the fixed point of reference, and the plane at right angles to the diameter of the sphere passing through that point with relation to which the position of the circle, if it be movable, is determined.

The fixed point of reference is, in all cases, either the zenith or

the pole; and the plane of reference, consequently, either that of the horizon or the equator.

22. **The astronomical clock.**—Since the immediate objects of all astronomical observation are motions and magnitudes, and since motions are measured by the comparison of space and time, one of the most important instruments of observation is the time-piece or chronometer, which is constructed in various forms, according to the circumstances under which it is used and the degree of accuracy necessary to be obtained. In a stationary observatory, a pendulum clock is the form adopted.

The rate of the astronomical clock is so regulated that, if any of the stars be observed which are upon the celestial meridian at the moment at which the hands point to $0^{h.}\ 0^{m.}\ 0^{s.}$, they will again point to $0^{h.}\ 0^{m.}\ 0^{s.}$ when the same stars are next seen on the meridian. The interval, which is called a sidereal day, is divided into twenty-four equal parts, called SIDEREAL HOURS. The hour-hand moves over one principal division of its dial in this interval. In like manner the MINUTE and SECOND-HANDS move on divided circles, each moving over the successive divisions in the intervals of a minute and a second respectively.

The pendulum is the original and only real measure of time in this instrument. The hands, the dials on which they play, and the mechanism which regulates and proportions their movements, are only expedients for registering the number of vibrations which the pendulum has made in the interval which elapses between any two phenomena. Apart from this convenience a mere pendulum unconnected with wheel work or any other mechanism, the vibrations of which would be counted and recorded by an observer stationed near it, would equally serve as a measure of time.

And this, in fact, is the method actually used in all exact astronomical observations. The *eye* of the observer is occupied in watching the progress of the object moving over the wires (11) in the field of view of the telescope. His *ear* is occupied in noting, and his mind in counting the successive beats of the pendulum, which in all astronomical clocks is so constructed as to produce a sufficiently loud and distinct sound, marking the close of each successive second. The practised observer is enabled with considerable precision in this way to subdivide a second, and determine the moment of the occurrence of a phenomenon within a small fraction of that interval. A star, for example, is seen to the left of the wire $m\,m'$ at s, *fig.* 7, at one beat of the pendulum, and to the right of it at s' with the next. The observer estimates

Fig. 7.

with great precision the proportion in which the wire divides the distance between the points s and s', and can therefore determine the fraction of a second after being at s, at which it was upon the wire $m\ m'$.

Although the art of constructing chronometers has attained a surprising degree of perfection, it is not perfect, and the RATE of even the best of such instruments is not absolutely uniform. It is therefore necessary from time to time to check the indications of the clock by observing its rate. If the clock were absolutely perfect, the pendulum would perform exactly 86,400 vibrations in the interval between two successive returns of the same star to the meridian. Now a good astronomical clock will seldom make so many as 86,401 nor so few as 86,399 vibrations in the interval. In the one case its rate would be too fast, and in the other too slow by 1 in 86,400. Even with such an erroneous rate the error thrown upon an observation of one hour would not exceed the 24th part of a second. If, however, the rate be observed, even this error may be allowed for, and no other will remain save the remote possibility of a change of rate since the rate was last ascertained.

23. **The transit instrument.**—All the most important astronomical observations are made at the moment when the objects observed are upon the celestial meridian, and in a very extensive class of such observations the sole purpose of the observer is to determine with precision the time when the object is brought to the meridian by the apparent diurnal motion of the firmament.

This phenomenon of passing the meridian is called the TRANSIT; and an instrument mounted in such a manner as to enable an observer, supplied with a clock, to ascertain the exact time of the TRANSIT is called a TRANSIT INSTRUMENT.

Such an instrument consists of a telescope so mounted that the line of collimation will be successively directed to every point of the celestial meridian when the telescope is moved upon its axis through 180°.

This is accomplished by attaching the telescope to an axis at right angles to its line of collimation, and placing the extremities of such axis on two horizontal supports, which are exactly at the same level, and in a line directed east and west. The line of collimation when horizontal will therefore be directed north and south; and if the telescope be turned on its axis through 180°, its line of collimation will move in the plane of the meridian, and will be successively directed to all points on the celestial meridian from the north to the pole, thence to the zenith, and thence to the south.

The instrument thus mounted is represented in *fig.* 8. Two stone piers are erected on a solid foundation standing east and

west. In the top of each of them is inserted a metallic support in the form of a Y to receive the cylindrical extremities of the trans-

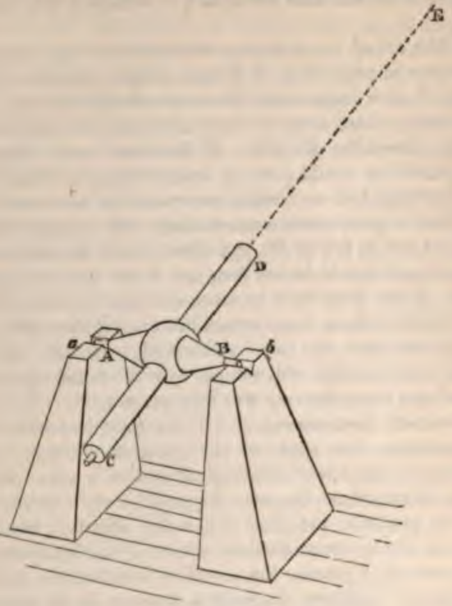


Fig. 8.

verse arms A B of the instrument. The tube of the telescope C D consists of two equal parts inserted in a central globe, forming part of the transversal axis A B. Thus mounted, the telescope can be made to revolve like a wheel upon the axis A B, and while it thus revolves its line of collimation would be directed successively to all the points of a vertical circle, the plane of which is at right angles to the axis A B. If the axis be exactly directed east and west, this vertical must be the meridian.

24. **Its adjustments.**—This, however, supposes three conditions to be fulfilled with absolute precision:

1st. The axis A B must be level.

2ndly. The line of collimation must be perpendicular to it.

3rdly. It must be directed due east and west.

In the original construction and mounting of the instrument these three conditions are kept in view, and are nearly, but cannot be exactly, fulfilled in the first instance. In all astronomical in-

struments the conditions which they are required to fulfil are only approximated to in the making and mounting; but a class of expedients called ADJUSTMENTS are in all cases provided, by which each of the requisite conditions, only *nearly* attained at first, are fulfilled with infinitely greater precision.

In all such adjustments two provisions are necessary: *first*, a method of detecting and measuring the deviation from the exact fulfilment of the requisite condition; and *secondly*, an expedient by which such deviation can be corrected.

25. **To make the axis level.**—If the axis A B be not truly level, its deviation from this direction may be ascertained by suspending upon it a SPIRIT LEVEL.

This consists of a glass tube nearly filled with alcohol or ether, liquids selected for the purpose, in consequence of the absence of all viscidity, their perfect mobility, and because they are not liable to congelation. The tube A B, *fig.* 9, is formed slightly con-

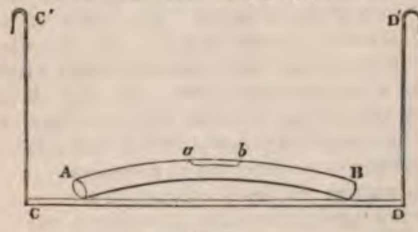


Fig. 9.

vex, and when it is placed horizontally with its convexity upwards, the *bubble* $a\,b$ produced by its deficient fulness will take the highest position, and therefore rest at the centre of its length. Marks are engraved on or attached to the tube at a and b indicating the centre of its length. The tube is attached to a straight bar C D, or so mounted as to be capable of being suspended from two points C′ D′, and is so adjusted that when the lower surface of the bar C D, or the line joining the two points of suspension C′ D′, is exactly level, the bubble will rest exactly in the centre of the tube between the marks a and b.

To ascertain whether a surface, or the line joining two proposed points, be level, the instrument is applied upon the one, or suspended from the other. If the bubble rest between the marks a and b, they are level; if not, that direction towards which it deviates is the more elevated, and it must be lowered, or the other raised. The operation must be repeated until the bubble is found to rest between the central marks a and b, whichever way the level be placed.

A level is provided for the transit instrument with two loops of suspension corresponding with the cylindrical extremities of the axis A B, *fig.* 8, so that its points of suspension may rest on these cylinders. If it be found that, when the level is properly suspended thus upon the axis, the bubble rests nearer to one extremity than the other, it will be necessary to raise that end from which it is more remote, or to lower that to which it is nearer.

To accomplish this, one of the supports in which the extremity A of the axis rests is constructed so as to be moved through a small space vertically by a finely constructed screw. This support is therefore raised or lowered by such means, until the bubble of the level rests between the central marks *a* and *b*, whichever way the level be suspended.

26. **To make the line of collimation perpendicular to the axis.**—It must be remembered, that the line of collimation is a line drawn from the centre of the object-glass to the middle wire in the field of view of the telescope. The centre of the object-glass is fixed relatively to the telescope, but the wires are so mounted that their position can be moved through a certain small space by means of a micrometer-screw. One end of the line of collimation, therefore, being movable, while the other is fixed, its direction may be changed at pleasure within limits determined by the construction of the eye-glass and its micrometer.

To ascertain whether the line of collimation is or is not at right angles to the line joining the points of support A and B, *fig.* 8, let any distant point be observed which may be bisected by the centre wire. Let the instrument be then reversed upon its supports, the end of the axis which rested on *a* being transferred to *b*, and that which rested on *b* to *a*, and let the same object be observed. If it still coincide with the centre wire, the line of collimation is in the proper direction; but if not, its distance from the wire will be twice the deviation of the line of collimation from the perpendicular, and the wires must be moved by the adjusting screw, until the centre wire is moved towards the object through half of its apparent distance from it.

To render this more clear, let A B, *fig.* 10, represent the direction of the axis, C D that of a line exactly at right angles to it, or the direction which is to be given to the line of collimation, and let CD′ represent the erroneous direction which that line actually has. Let S be a distant object to which it is observed to be directed, this object being seen upon the centre wire. If the instrument be reversed, the line CD′ will have the direction CD″, deviating as much from CD to the right as it before deviated to the left. The object S will now be seen at a distance to the left of the centre wire which measures the angle D′CD″, which is twice the

angle D C D′, or the deviation of the line of collimation from the perpendicular D C.

27. **To render the direction of the supports due east and west.**—This is in some cases accomplished by a MERIDIAN MARK, which is a distinct object, such as a white vertical line painted on a black ground, erected at a sufficient distance from the instrument in the exact meridian of the observatory. If, on directing the telescope to it, it is seen on the one side or the other of the middle wire (which ought to coincide with the meridian), the direction of the axis A B, *fig.* 8., will deviate to the same extent from the true east and west, since it has been already, by the previous adjustments, rendered perpendicular to the line of collimation. The entire instrument must therefore be shifted round, until the meridian mark coincides with the middle wire. This is accomplished by a provision made in the support on which the extremity of the axis B, *fig.* 8., rests, by which it has a certain play in the horizontal direction urged by a fine screw. In this way the axis A B is brought into the true direction east and west, and therefore the line of collimation into the true meridian.

Fig. 10.

It will be observed that, in explaining the second adjustment, it has been assumed that the deviations are not so great as to throw the object S out of the field of view after the instrument is reversed. This condition in practice is always fulfilled, the extent of deviation left to be corrected by the adjustments being always very small.

28. **Micrometer wires — method of observing a transit.**— In the focus of the eye-piece of the transit instrument, the system of micrometer wires (11), already mentioned, is placed. This consists commonly of 5 or 7 equidistant wires, placed vertically at equal distances, and intersected at their middle points by a horizontal wire, as represented in *fig.* 7. In instruments which are adapted to the chronographic method of observing transits, the number of wires is considerably increased. When the instrument has been adjusted, the middle wire $m m'$ will be in the plane of the meridian, and when an object is seen upon it, such object will be on the celestial meridian, and the wire itself may be regarded as a small arc of the meridian rendered visible.

The fixed stars, as will be explained more fully hereafter, appear in the telescope, no matter how high its magnifying power be, as mere lucid points, having no sensible magnitude. By the diurnal motion of the firmament, the star passes successively over all the wires, a short interval being interposed between its passages. The observer, just after the star approaching the meridian enters the field of view, proceeds to count the *seconds* of the clock by his ear. He observes, in the manner already explained, to a fraction of a second, the instant at which the star crosses each of the wires; and taking a mean of all these times, he obtains, with a great degree of precision, the instant at which the star passed the middle wire, which is the time of the transit. The hour and minute indicated by the clock is noted after the observation.

By this expedient the result has the advantage of as many independent observations as there are parallel wires. The errors of observation being distributed, are proportionally diminished.

When the sun, moon, or a planet, or, in general, any object which has a sensible disk, is observed, the time of the transit is the instant at which the centre of the disk is upon the middle wire.

This is obtained by observing the clock-time when the western and eastern edges of the disk come in contact respectively with each of the vertical wires. Taking first a mean of all the observed clock-times of the transit of the western edge, the time when it is on the middle wire is found; and in like manner, the mean of all the observed clock-times of the transit of the eastern edge will give the time when that edge is also on the middle wire; the mean of these transits of the two edges, therefore, determines the clock-time of the transit of the centre of the disk over the middle wire, or a mean of all the observed clock-times of the transit of both edges will give the same result.

By day the wires are visible, as fine black lines intersecting and spacing out the field of view. At night they are rendered visible by a lamp, by which the field of view is faintly illuminated.

In many observatories transits are also observed by the chronographic method, and recorded by the aid of galvanism on a revolving cylinder. In this case, the clock is provided with means for sending a galvanic signal to the recording apparatus at every vibration of the pendulum, causing a puncture to be made on the paper with which the cylinder is covered. This series of punctures form one long spiral line, the prickers being attached to a travelling frame, which is carried by an uniform-motion clock, which at the same time causes the cylinder to revolve. The office of the observer is simply to press an ivory key when the star is passing each wire in the field of view; this completes the galvanic circuit and causes a puncture for each wire observed to be made

between the series of clock punctures. It is a matter of very little trouble to extract the exact second and fraction of a second at which the separate observations were made.

The results from this method are considered more trustworthy than those determined by "eye and ear." From a mean of 101 transits observed at Greenwich, it was found that the probable error of one transit by the chronographic method was $0^s{\cdot}017$, while by the "eye and ear" it amounted to $0^s{\cdot}028$. In another determination on a different principle, the excess in the same direction amounted to $0^s{\cdot}014$. Though this amount may seem insignificant to the reader, nevertheless it is of considerable importance in connection with astronomical observations.*

29. **Apparent motion of objects in the field of view.**—Since the telescope reverses the objects observed, the motion in the field will appear to be from west to east, while that of the firmament is from east to west. An object will therefore enter the field of view on the west side, and, having crossed it, will leave it on the east side.

Since the sphere revolves at the rate of $15°$ per hour, $15'$ per minute, or $15''$ per second of time, an object will be seen to pass across the field of view with a motion absolutely uniform, the space passed over between two successive beats of the pendulum being invariably $15''$.

Thus, if the moon or sun be in or near the equator, the disk will be observed to pass across the field with a visible motion, the interval between the moments of contact of the western and eastern edges with the middle wire being $2^m\ 8^s$, when the apparent diameter is $32'$. Thus, the disk appears to move over a space equal to half its own diameter in $1^m\ 4^s$.

30. **Circles of declination, or hour circles.**—Circles of the celestial sphere which pass through the poles are at right angles to the celestial equator, and are on the heavens exactly what meridians are upon the terrestrial globe. They divide the celestial equator into arcs which measure the angles which such circles form with each other. Thus, two such circles which are at right angles include an arc of $90°$ of the celestial equator, and two which form with each other an angle of $1°$ include between them an arc of $1°$ of the celestial equator. These CIRCLES OF DECLINATION, or HOUR CIRCLES as they are called, are carried round by the diurnal motion of the heavens, and are brought in succession to coincide with the celestial meridian, the intervals between the moments of their coincidence with the meridian being always proportional to the angle they form with each other, or, what is the same, to the arc of the celestial equator included between them. Thus, if two circles of

* *Astron. Soc. Notices*, Vol. xx. p. 86.

declination form with each other an angle of 30°, the interval between the moments of their coincidence with the meridian will be two sidereal hours.

The relative position of the circles of declination with respect to each other, and to the meridian, and the successive positions assumed by any one such circle during a complete revolution of the sphere, will be perceived and understood without difficulty by the aid of a celestial globe, without which it is scarcely possible to obtain any clear or definite notion of the apparent motions of celestial objects.

31. **Right ascension.**—The arc of the celestial equator between any circle of declination and a certain point on the equator called the FIRST POINT OF ARIES, is called the RIGHT ASCENSION of all objects through which the circle of declination passes. This arc is always understood to be measured from the point where the circle of declination meets the celestial equator *westward*, that is, in the direction of the apparent diurnal motion of the heavens, and it may extend, therefore, over any part whatever of the equator from 0° to 360°.

Right ascension is expressed sometimes according to angular magnitude, in degrees, minutes, and seconds; but since, according to what has been explained, these magnitudes are proportional to the time they take to pass over the meridian, right ascension is more frequently expressed immediately by this time. Thus, if the right ascension of an object is $15° 15' 15''$, it will be expressed also by $1^h 1^m 1^s$.

In general, right ascension expressed in degrees, minutes, and seconds may be reduced to time by dividing it by 15; and if it be expressed in time, it may be reduced to angular language by multiplying it by 15.

The difference of right ascensions of any two objects may be ascertained by the transit instrument and clock, by observing the interval which elapses between their transits over the meridian. This interval, whether expressed in time or reduced to degrees, is their difference of right ascension.

Hence, if the right ascension of any one object be known, the right ascension of all others can be found.

32. **Sidereal clock indicates right ascension.**—If the hands of the sidereal clock be set to $0^h 0^m 0^s$ when the first point of Aries is on the meridian, they will at all times (supposing the rate of the clock to be correct) indicate the right ascension of such objects as are on the meridian. For the motion of the hands in that case corresponds exactly with the apparent motion of the meridian on the celestial equator produced by the diurnal motion of the heavens. While 15° of the equator pass the meridian the hands move through 1^h, and other motions are made in the same proportion.

[redacted]

33. **The mural circle.**—The transit instrument and sidereal clock supply means of determining with extreme precision the instant at which an object passes the meridian; but the instrument is not provided with any accurate means of indicating the point at which the object is seen on the meridian. A circle is sometimes, it is true, attached to the transit by which the position of this point may be roughly observed; but to ascertain it with a precision proportionate to that with which the transit instrument determines the right ascensions, requires an instrument constructed and mounted for this express object in a manner, and under conditions, altogether different from those by which the transit instrument is regulated. The form of instrument adopted in the most efficiently furnished observatories for this purpose is the MURAL CIRCLE.

This instrument is a graduated circle, similar in form and principle to the instrument described in (13). It is centred upon an axis established in the face of a stone pier or *wall* (hence the name) erected in the plane of the meridian. The axis, like that of a transit instrument, is truly horizontal, and directed due east and west. Being by the conditions on which it is first constructed and mounted, *very nearly* in this position, it is rendered *exactly* so by two adjustments, one of which moves the axis vertically, and the other horizontally, by means of screws, through spaces which, though small, are still large enough to enable the observer to correct the slight errors of position incidental to the workmanship and mounting.

The instrument, as mounted and adjusted, is represented in perspective in *fig.* 11, where A is the stone wall to which the instrument is attached, D the central axis on which it turns; and F G the telescope, which does not move upon the circle, but is immovably attached to it, so that the entire instrument, including the telescope, turns in the plane of the meridian upon the axis D.

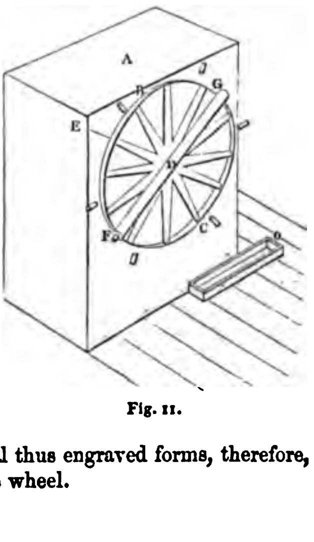


Fig. 11.

A front view of the circle in the plane of the instrument is given in *fig.* 12.

The graduation is usually made on the edge, and not on the face limb. The hoop of metal thus engraved forms, therefore, what may be called the tire of the wheel.

A trough *o*, containing mercury, is placed on the floor in a convenient position in the plane of the instrument, on the surface of

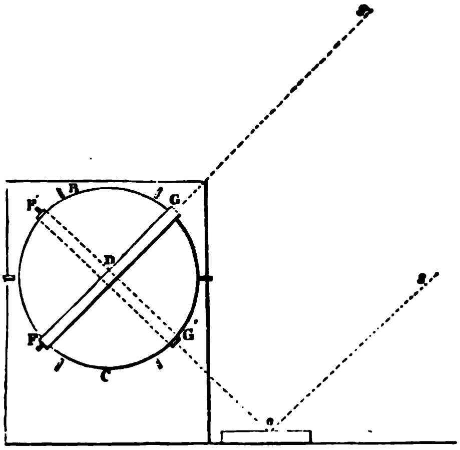


Fig. 12.

which are seen, by reflection, the objects as they pass over the meridian. The observer is thus enabled to ascertain the directions, as well of the images of the objects reflected on the mercury, as of the objects themselves, the advantage of which will presently appear.

Convenient ladders, chairs, and couches, capable of being adjusted by racks and other mechanical arrangements, at any desired inclination, enable the observer, with the utmost ease and comfort, to apply his eye to the telescope, no matter what be its direction.

In the Greenwich observatory, the mural circles formerly in use were six feet in diameter, and consequently about 226 inches in circumference. Each degree upon the circumference measuring, therefore, above six-tenths of an inch, admits of extremely minute subdivision.

The divisions on the graduated edge of the instrument are numbered as usual from 0° to 360° round the entire circle. The position which the direction of the line of collimation of the telescope has with relation to the 0° of the limb is indifferent. Nothing is necessary except that this line, in moving round the axis D of the instrument, shall remain constantly in the plane of the meridian. This condition being fulfilled, it is evident that, as the circle revolves, the line of collimation will be successively directed to every point of the meridian when presented upwards, and to every

point of its reflected image on the mercury when presented downwards.

34. **Method of observing with it.**—The position of the instrument when directed successively to two objects on the meridian, or to their images reflected on the mercury, being observed, the angular distance, or the arc of the meridian between them, will be found by ascertaining the arc of the graduated limb of the instrument, which passes before any fixed point or index, when the telescope is turned from the direction of the one object to the direction of the other.

35. **Compound microscopes—their number and use.**—This arc is observed by a compound microscope (16), attached to the wall or pier, and directed towards the graduated limb. The manner in which the fraction of a division of the limb is observed by this expedient has been already explained. But to give greater precision to the observation, as well as to efface the errors which might arise, either from defective centreing, or from the small derangement of figure that might arise from the flexure produced by the weight of the instrument, several compound microscopes—generally six—are provided at equal distances around the limb, so that the observer is enabled to note the position of six indices. The six arcs of the limb which pass under them being observed, are equivalent to six independent observations, the mean of which being taken, the errors incidental to them are reduced in proportion to their number.

36. **Circle primarily a differential instrument.**—The observations, however, thus taken are, strictly speaking, only differential. The arc of the meridian between the two objects is determined, and this arc is the difference of their meridional distances from the zenith or from the horizon; but unless the positions which the six indices have, when the line of collimation is directed to the zenith or horizon, be known, no positive result arises from the observations; nor can the absolute distance of any object, either from the horizon or the zenith, be ascertained.

37. **Method of ascertaining the horizontal point.**—The "reading," as it is technically called, at each of the microscopes, in any proposed position of the instrument, is the distance of that microscope from the zero point of the limb. Now it is evident that half the sum of the two readings at any microscope, when the telescope is successively directed to an object and its image on the mercury, will be the reading at the same microscope when the line of collimation is horizontal.

38. **Method of observing altitudes and zenith distances.**—The mean of the readings of all the microscopes, when the telescope is directed to the horizon, known as the *horizontal point*, being thus

determined, forms a necessary datum in all observations of the altitudes or zenith distances of objects. To determine the altitude of an object, the telescope must be directed to it, so that it shall be seen nearly bisected by the horizontal wire, near the centre of the field of view; then by means of a slow motion tangent-screw it is brought on to the wire and exactly bisected by it, the instrument being fixed by a clamp. The six microscopes are then read, a mean of which is taken to obtain a circle reading free from any error due to excentricity of the circle. The reading when the telescope is horizontal being known, the difference between these two readings gives the altitude.

The altitude of an object being determined, its zenith distance may be found by subtracting the altitude from 90°.

39. **Method of determining the position of the pole and equator.**—The mural circle may be regarded as the celestial meridian reduced in scale, and brought immediately under the hands of the observer, so that all distances upon it may be submitted to exact examination and measurement. Besides the zenith and horizon, the positions of which, in relation to the microscopes, have just been ascertained, there are two other points of equal importance, the pole and the equator, which should also be established.

The stars which are so near the celestial pole that they never set, are carried by the diurnal motion of the heavens round the pole in small circles, crossing the visible meridian twice, once above and once below the pole. Of all the circumpolar stars, the most important and the most useful to the observer is the pole star, both because of its close proximity to the pole, from which its distance is only $1\frac{1}{2}$°, and because its magnitude is sufficiently great to be visible with the telescope in the day. This star, then, crosses the meridian above the pole and below it, at intervals of twelve hours sidereal time, and the true position of the pole is exactly midway between the two points where the star thus crosses the meridian.

If, therefore, the readings of the six microscopes be taken when the pole star makes its transit above and below the pole, their readings for the pole itself will be half the sum of the former for each microscope.

The readings for the pole being determined, those which correspond to the point where the celestial equator crosses the meridian may be found by subtracting the former from 90°.

When the positions of the microscopes in relation to the pole and equator are determined, the latitude of the observatory will be known, since it is equal to the altitude of the celestial pole.

40. **All circles of declination represented by the circle.**—Since the circles of declination, which are imagined to surround the heavens, are brought by the diurnal motion in succession to coincide

with the celestial meridian (30), and since that meridian is itself represented by the mural circle, that circle may be considered as presenting successively a model of every circle of declination; and the position of any object upon the circle of declination is represented on the mural circle by the position of the telescope when directed to the point of the meridian at which the object crosses it.

If the object have a fixed position on the firmament, it is evident that it will always pass the meridian at the same point; and if the telescope be directed to that point and maintained there, the object will be seen at the intersection of the wires regularly after intervals of twenty-four hours sidereal time.

41. **Declination and polar distance of an object.**—The distance of an object from the celestial equator, measured upon the circle of declination which passes through it, is called its DECLINATION, and is NORTH or SOUTH, according to the side of the equator at which the object is placed.

The declination of an object is ascertained with the mural circle in the same manner and by the same observation as that which gives its altitude. The readings of the microscopes for the object being compared with their readings for the pole (39), give the polar distance of the object; and the difference between the polar distances and 90° gives the declination.

Thus the polar distance and declination of an object are to the equator exactly what its altitude and zenith distance are to the horizon. But since the equator maintains always the same position during the diurnal motion of the heavens, the declination and polar distance of an object are not affected by that motion, and remain the same, while the altitude and zenith distances are constantly changing.

42. **Position of an object defined by its declination and right ascension.**—The position of an object on the firmament is determined by its declination and right ascension. Its declination expresses its distance north or south of the celestial equator, and its right ascension expresses the distance of the circle of declination upon which it is placed from a certain defined point upon the celestial equator.

It is evident, therefore, that declination and right ascension define the position of celestial objects in exactly the same manner as latitude and longitude define the position of places on the earth. A place upon the globe may be regarded as being projected on the heavens into the point which forms its zenith; and hence it appears that the latitude of the place is identical with the declination of its zenith.

43. **Equatorial instrument.** — The exact direction of the axis of the celestial sphere being ascertained, it is possible to construct

an apparatus which shall be capable of revolving upon a fixed axis, the direction of which shall coincide with that of the sphere; so that if a telescope were fixed in the direction of this axis, its line of collimation would exactly point to the celestial pole.

Upon this axis, thus directed and fixed, suppose a telescope to be so mounted that it may be placed with its line of collimation at any desired angle with the axis, and let a properly graduated arc be provided, by which the magnitude of this angle may be measured with all practicable precision.

Thus, let A A′, *fig.* 13, represent the direction of the axis on which the instrument is made to revolve. The line A A′, if con-

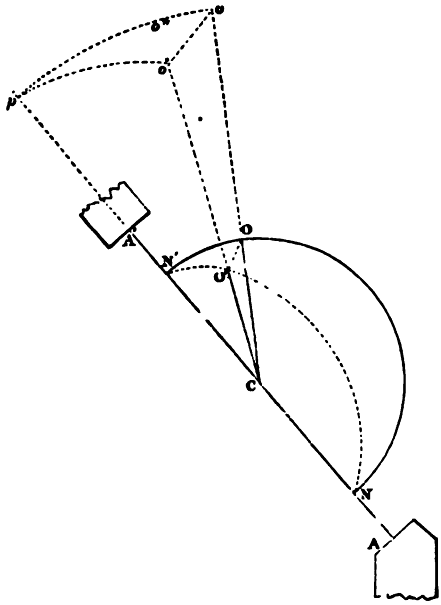


Fig. 13.

tinued to the firmament, would pass through the pole *p*. Let C O represent the line of collimation of a telescope, so attached to the axis at C that it may be placed at any desired angle with it; which may be accomplished by placing a joint at C on which the telescope can turn. Let N O N′ be a graduated arc, to which the telescope is attached at O, and which turns with the telescope round the axis A A′. When the telescope, being fixed at any proposed angle O C A′

with the axis, is turned round A A′, the line of collimation describes a cone of which C is the vertex and C A′ the axis, and the extremity O describes an arc O O′ of a circle at a distance from N′ measured by the angle O C A′.

If the line of collimation C O or C O′ be imagined to be continued to the heavens, it will describe, as the telescope revolves, a circle *o o′* on the firmament corresponding to the circle O O′, and at the same angular distance *o p*, *o′ p* from the celestial pole *p*, as the end O or O′ of the line of collimation of the telescope is from N′ or A′. In short, the angle O C N′ equally measures the two arcs, the celestial arc *o p* and the instrumental arc O N′.

The instrument thus described in its principle is one of most extensive utility in observatories, and is called an EQUATORIAL.

In its practical construction it is very variously mounted, and is generally acted upon by clock-work, which imparts to it a motion round the axis A A′, corresponding with the rotation of the celestial sphere.

One of the many mechanical arrangements by which this may be effected is represented in *fig.* 14, as given by the Astronomer Royal, in his lectures delivered at the Ipswich Museum.

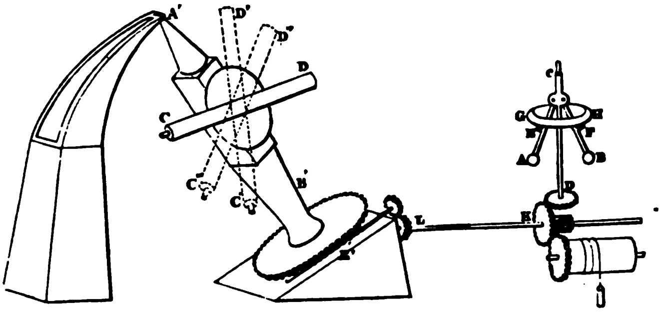


Fig. 14.

The instrument is supported upon pivots, so that its axis A′B′ shall coincide exactly with the direction of the celestial axis. The telescope C D turns upon a joint at the centre, so that different directions such as C′ D′, C″ D″, may be given to it. The motion upon its axis is imparted to it by wheel-work E′L K, impelled by clockwork, as already mentioned.

Having explained the general construction of the principal instruments used in astronomical observations, we will now devote the remainder of this chapter to a description of a few celebrated

instruments of each class, which are remarkable for their stability and magnitude.

44. **Sir W. Herschel's forty-feet reflector.**—This instrument, which is memorable as the first ever constructed upon a scale of such stupendous magnitude, and still more so for the vast discoveries made with it by its illustrious inventor and constructor, is represented in Plate II. It is not necessary to give a detailed account of this celebrated instrument, as it has been dismantled since the removal of Sir John Herschel from Slough, and has not been remounted. The total length of the telescope tube was 39 ft. 4 in. and its clear diameter 4 ft. 10 in., the diameter of the speculum being 4 ft., with a reflecting surface of 12·566 square feet.

45. **The Rosse telescopes.** — The lesser instrument, with its mounting, is represented in Plate III. The speculum is 3 feet aperture, and 7·068 square feet reflecting surface. The length of the telescope is 27 feet. It is erected upon the pleasure grounds at Parsonstown Castle, the seat of its illustrious constructor. The weight of metal in the speculum is about 13 cwt.

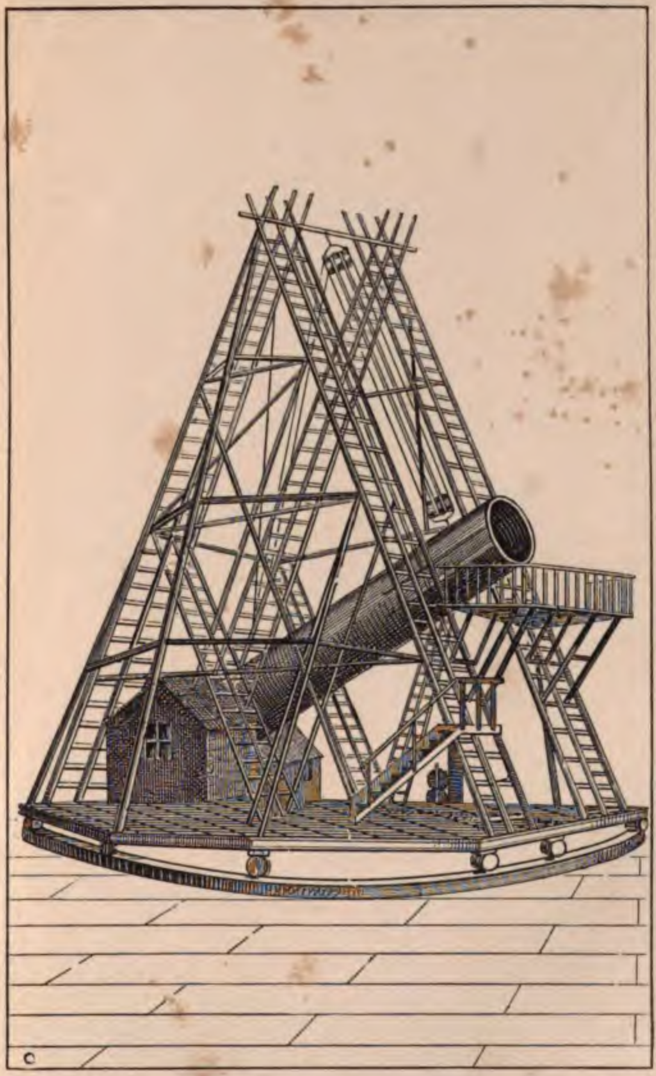
But the most stupendous instrument of celestial investigation, and by far the largest and most powerful ever constructed, is represented in Plates IV. and V. from drawings made for this work under the superintendence of his Lordship himself. Plate IV. presents a south, and Plate V. a north view of the instrument.

The clear aperture is 6 ft., and consequently the magnitude of the reflecting surface is 28·274 square feet, being greater than that of Herschel's great telescope in the ratio of 7 to 3.

The instrument is at present used as a Newtonian telescope (O. 504), that is to say, the rays proceeding along the axis of the great speculum are received at an angle of 45° upon a second small speculum, by which the focus is thrown towards the side of the tube where the eye-piece is directed upon them. Provision is, however, made to use the instrument also as a Herschelian telescope.

The great tube is supported at the lower end upon a massive universal joint of cast-iron, resting on a pier of stone-work buried in the ground, and is so counterpoised as to be moved with great ease in declination. In all such instruments, when it is required to direct them to an object, they are first brought to the desired direction by some expedient capable of moving them more rapidly, and they are afterwards brought exactly upon the object by a slower and more delicate motion. In this case, the quick motion is given by a windlass, worked upon the ground by an assistant at the command of the observer. The slow motion is imparted by a mechanism placed under the hand of the observer.

The extreme range of the telescope in right ascension, when di-

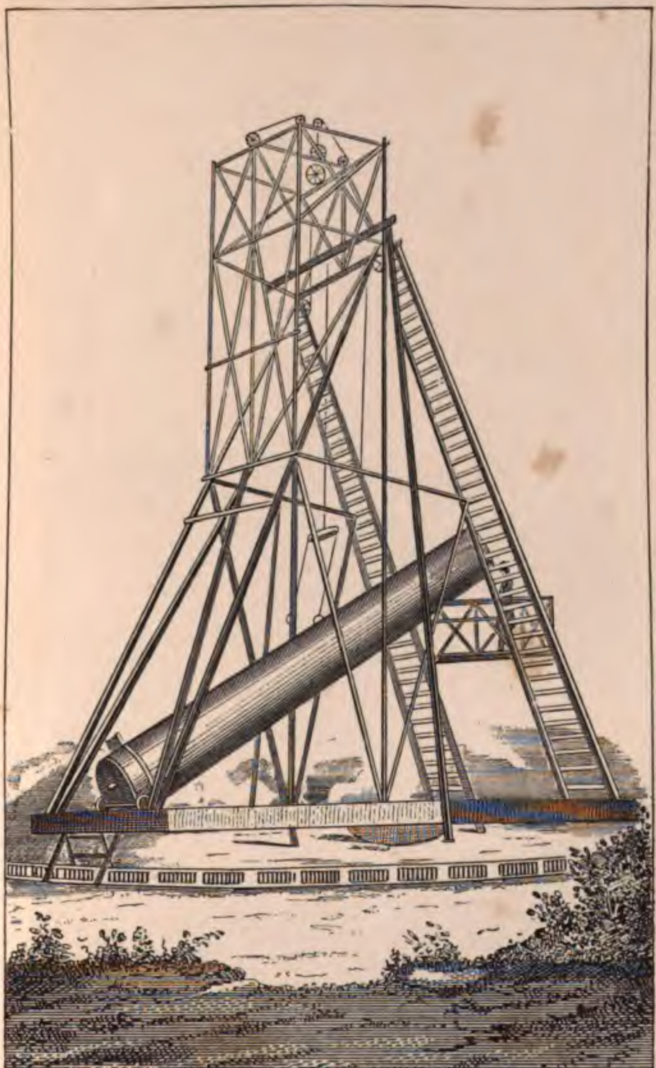


SIR W. HERSCHEL'S GREAT TELESCOPE.

Focal length, 40 feet; aperture, 4 feet.

[redacted]

III.

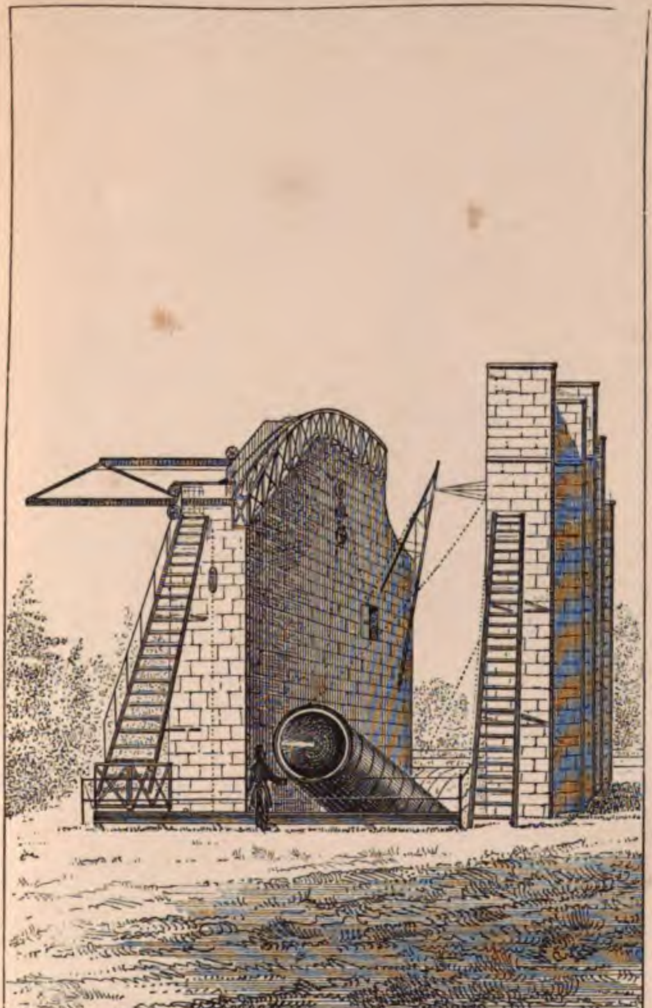


THE LESSER ROSSE TELESCOPE.

Focal length, 27 ft. : aperture, 3 ft.

[redacted]

IV.

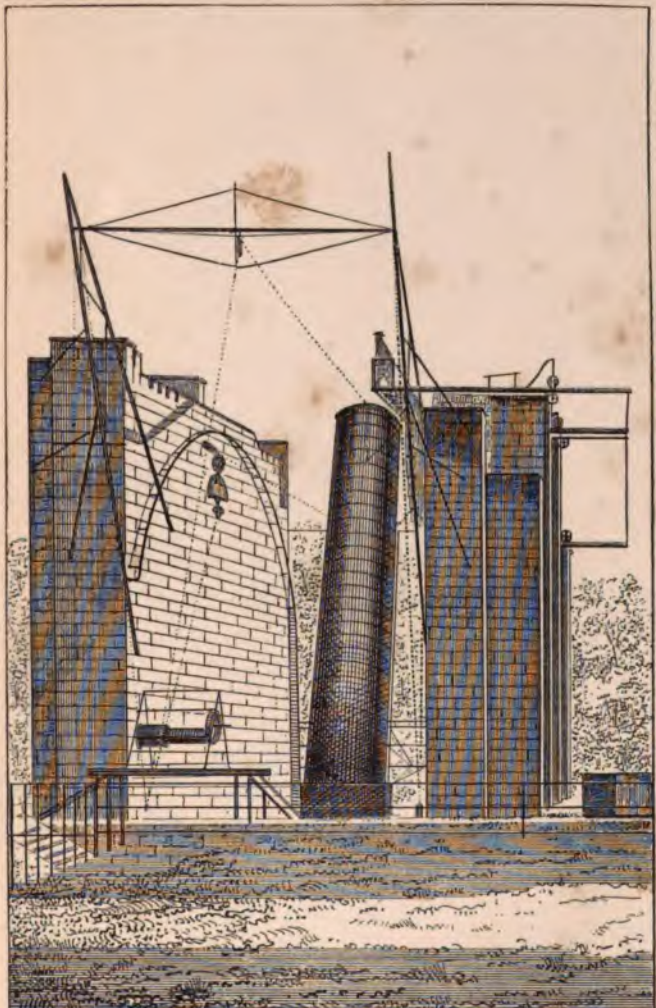


THE GREAT ROSSE TELESCOPE (South Side).

Focal length, 53 feet; aperture, 6 feet.

[redacted]

V.



THE GREAT ROSSE TELESCOPE (North Side).

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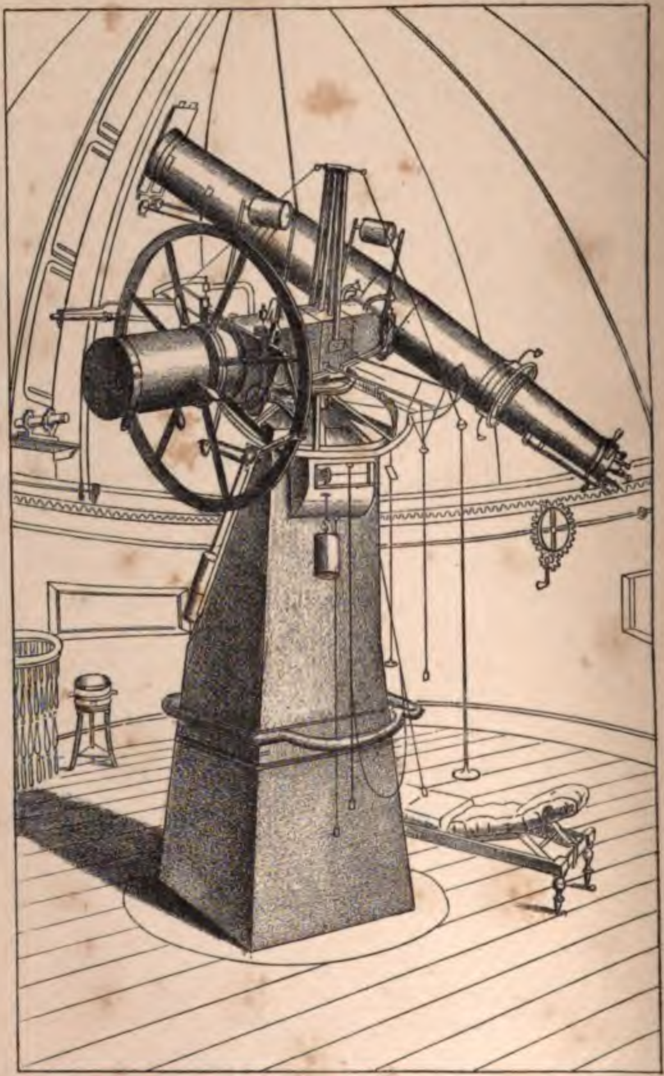
VI.



THE OXFORD HELIOMETER.

rected to the equator, is 1 hour in time, or 15° in space; but when directed to higher declinations, its range is more extensive.

The tube is slung entirely by chains, and is perfectly steady, even in a gale of wind.

When presented to the south, the tube can be lowered until it is nearly horizontal; towards the north, it can only be depressed to the altitude of the pole. The apparatus of suspension is so arranged that the instrument may be worked as an equatorial, and it is even intended to apply a clock-work mechanism to it.

The horizontal axis of the great universal joint, by which the lower end is supported, carries an index pointing to polar distance, and playing on a graduated arc of 6 feet radius. By this means, the telescope is easily set in polar distance. The same object is also attained, and with greater precision, by a 20-inch circle attached to the instrument.

Two specula have been provided for the telescope, one of which contains 3½, and the other 4 tons of metal, the composition of which is 126 parts in weight of copper to 57½ of tin.

The great tube is of wood hooped with iron, and is 7 feet in diameter, and 52 in length. The side-walls, 12 feet distant from the tube, are 72 feet in length, 48 feet in height on the outside, and 56 feet in the inside. These walls are built in the plane of the meridian.

The observer stands in one or other of four galleries, the three highest of which are drawn out from the western wall, while the fourth or lowest has for its base an elevating platform, along the surface of which a gallery is moved from wall to wall by a mechanism at the command of the observer.

46. **The Oxford heliometer.**—This class of instrument, which derives its name from having been first applied to the measurement of the diameter of the sun, consists of a telescope mounted as an equatorial, the object-glass of which is divided along a plane passing through its optic axis, each half of the lens being capable of being moved in its own plane, so that the axes of the two semi-lenses, being always parallel to each other and to the axis of the telescope, may be within certain limits separated from each other, more or less, at the pleasure of the observer.

From what has been explained in general of the structure of an equatorial instrument (43), and from the drawing of this instrument given in Plate VI., the provisions for the direction of the telescope in right ascension and declination will be easily comprehended. The polar axis, round which the instrument turns in right ascension, is fixed upon the face of a block of Portland stone, and the graduated circle measuring right ascension is seen at the top and at right angles to the polar axis. This circle receives its

motion in the usual way, from clockwork, which is attached to the stone pier, and which, with its impelling suspended weight, is seen in the drawing. Rods are provided by which the observer can, at pleasure, set the clock going, or stop it, and connect it with, or disengage it from, the equatorial circle.

The circle for indicating polar distance or declination is placed upon the horizontal axis of the instrument, and also appears in the drawing at the side opposite to that at which the telescope is attached.

The object-glass of this instrument, sometimes called the "divided object-glass micrometer," supplies a very accurate method of measuring angles which do not exceed a certain limit of magnitude.

It appears by the principles of optics, that when the image of a distant object is produced by a lens, *each point* of such image is formed by rays which proceed from *every point* of the lens. If, therefore, a part of the lens be covered by an opaque body or cut away, *each point* of the image will still be formed by the rays which proceed from *every point of the lens which is not covered or cut away.* The only difference which will be observed in the image will be, that it will be less strongly illuminated, being deprived of the rays which it received from the part of the lens covered or cut away, and that it will be less distinct in consequence of certain effects of diffraction which need not be noticed here.

It follows, therefore, that half a lens will produce at the focus an image of a distant object, and if two halves of the same lens be placed concentrically, they will form two images, the exact superposition of which will, in fact, constitute the image formed by the complete lens. But if the two halves be not concentrical, the two images will not be superposed, but will be separated by a space corresponding with, and proportional to, the distance between the centres of the two half lenses. Thus, if the lenses be directed to the sun, two images of the solar disk will be produced at the focus of the lenses, and these images may be shifted in their positions, the centres approaching to, or receding from, one another, according as the centres of the two half lenses approach to, or recede from, each other; and if the angular distance through which either image moves can be known, it is easy to see how, by this means, the apparent diameter of such an object as the sun can be measured. For this purpose, let the two half lenses be first placed concentrically, so that the two images shall be exactly superposed. Then let one of the two lenses be moved (the edges of the semi-lenses being always maintained in contact), until the image, formed by the semi-lens, which is moved, shall be removed to such a position that the two images shall touch each other externally, as in

fig. 15. In that case it is evident that the centre of the image formed by the semi-lens which has been moved, must have moved over a space equal to the diameter of the image of the disk, and if the angular value of such space be known, the apparent diameter of the sun will be known.


Fig. 15.

This was the application of the divided object-glass, from which the heliometer took its name. The instrument, however, has since been applied to so many other important purposes, that the name has ceased to express its uses.

The two semi-lenses forming the object-glass of the heliometer are set edge to edge in strong brass frames, which slide in grooves with a smooth and even motion. They are moved by fine screws which, by the intervention of cog-wheels, are turned by a pair of rods which pass along the tube of the telescope. The separation of the centres of the semi-lenses, and consequently the angular distance between the two images, is measured according to a known scale by the number of turns and parts of a turn of the screw which are necessary to produce the separation or to bring back the semi-lenses to a concentrical position, if they are separated.

It is obvious, that the same principle will be applicable to measure the apparent angular distance between any two objects, such as two stars, which are so near each other that they may be seen together in the field of view of the telescope. For this purpose, let the semi-lenses be first placed concentrically. The two stars S and S′ will then be seen in their proper positions in the field. Let the semi-lenses be then moved so that two images of each star will be visible. Let the motion be continued until the image of the star S by one semi-lens coincides with the image of the other star S′ by the other semi-lens. The angular distance corresponding to the separation of the lenses will then be the angular distance between the stars.

In this heliometer a very ingenious contrivance is introduced to enable the observer to read the scale by which the angular magnitude corresponding to the separation of the centres of the semi-lenses is indicated. This is accomplished by placing a scale behind the object-glass in the interior of the telescope tube, so that it can be read by means of a long microscope, the eye-glass of which is placed near the eye-piece of the telescope. This interior scale is illuminated by a piece of platinum wire placed near it, which is rendered incandescent by a galvanic current transmitted upon it at pleasure by the observer. This current is produced by a Smee's battery placed in a room below that containing the heliometer.

A very splendid instrument of this class has been erected at the Pulkowa observatory.

47. **The Greenwich transit-circle.**—This instrument, which has superseded the 10-feet transit instrument and 6-feet mural circle at the Royal Observatory since the beginning of 1851, has been constructed on a vast scale of magnitude aud stability. The aperture of the object-glass of the former transit being about 5 inches, while that of the mural circle measured only 4 inches, made it generally impossible to obtain trustworthy observations of the numerous small planets which had been lately discovered. For the credit therefore of the national observatory, it was considered advisable to erect a more powerful instrument with an object-glass of increased aperture, and in the form of a transit-circle.

A perspective view of this instrument is presented in Plate VII., made from original drawings taken by permission of the Astronomer Royal.

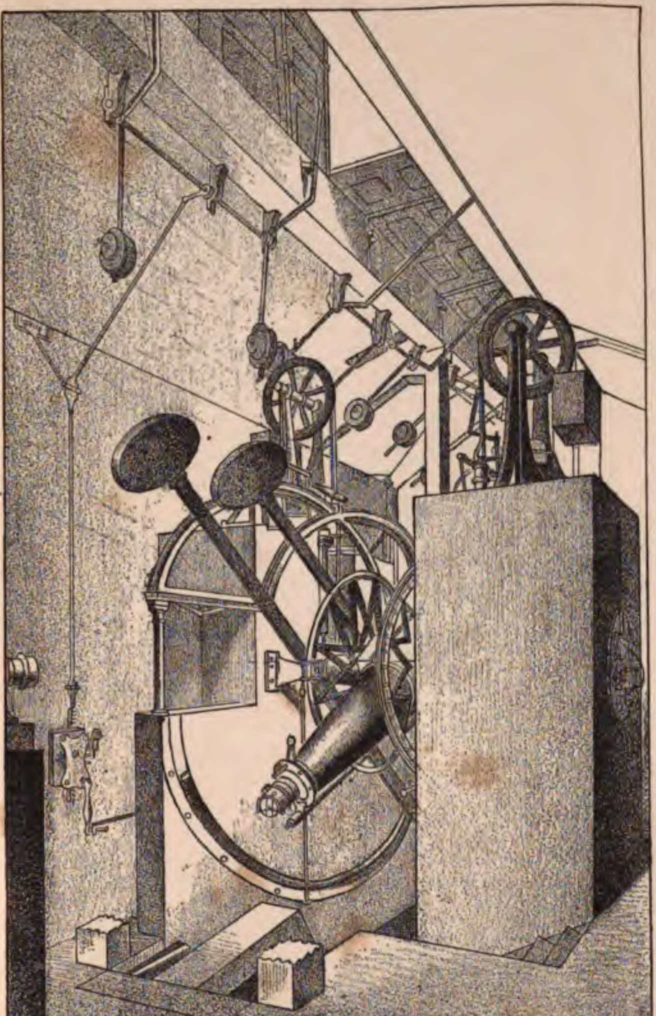
It was also found, by the results of observations made with the 10-feet transit instrunent that, although it was the best of its class, and had been constructed with the greatest degree of artistic skill, it was nevertheless so unstable as to produce errors in the determination of time, which it was possible, and therefore desirable, to remove by introducing improved principles of construction, which will be presently explained in relation to another instrument previously erected at the Observatory.

This instrument consists of a telescope fixed between two parallel circles, one of which is graduated, resting on horizontal supports, placed on two stone piers, so that the line of collimation moves in the plane of the meridian.

The telescope tube, which is nearly 12 feet long, consists of a hollow cube of metal, to which two large cones are bolted by means of flanges. At the smaller end of one cone is the object-glass, and in that of the other the eye-piece. Each of these cones weighs 1·75 cwt., and the central cube with its pivots weighs 8 cwt. The whole length of the horizontal axis of the instrument is 6 feet, the diameter of each of the pivots being 6 inches. The object-glass is 8 inches aperture, its optical power being sufficient for the observation of the faintest objects which are presented in the ordinary course of meridional observations.

The parallel circles between which the telescope is fixed, are each 6 feet in diameter, and are firmly attached to cylindrical bands, one on each side of the central cube of the telescope. The clamping apparatus is applied to the eastern circle, and the western circle is graduated. The reading-off is effected by means of six microscopes, each 45 inches in length, which are simply inclined perforations through the western pier, having their eye-pieces arranged on the

VII.



GREENWICH TRANSIT CIRCLE.

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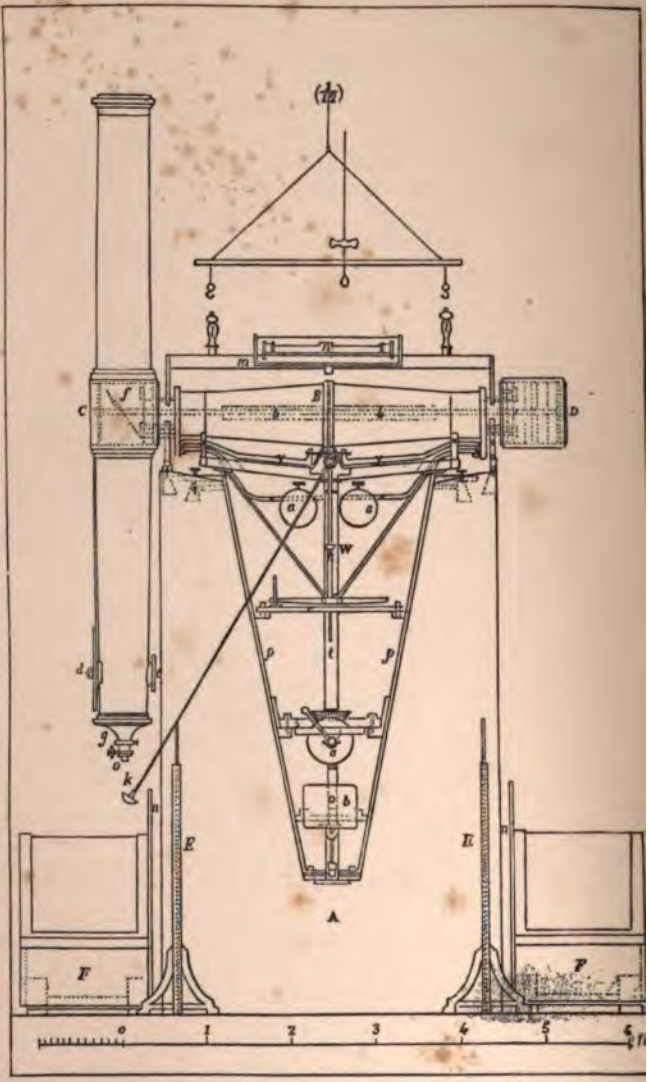


PULKOWA PRIME VERTICAL INSTRUMENT.

back of the western pier in a circle whose diameter is 21 inches, and their object-glasses on the eastern side arranged in a circle about 5 feet in diameter, pointing to the divisions on the limb of the graduated circle.

The graduation of the circle is such as to show approximately zenith distances; while a pointer fixed to a block projecting from the lower part of the pier, directed to another graduated band on the outer or eastern side of the circle, is used for setting the telescope, and gives approximately north polar distances. A small finder, with a large field of view, is attached to the side of the cone near the eye-piece, for the convenience of setting for large objects.

A large gas-light conveniently placed, illuminates, by means of a lens for each microscope, the graduated arc of the circle at the divisions which are viewed by the several microscopes, and also the field of the telescope.

A variety of other provisions and adjustments are attached to the instrument, which it would be impossible to render clearly intelligible without reference to the instrument itself, or very detailed and elaborate drawings of its several parts, which our limits do not permit us to introduce here.

48. **The Pulkowa prime vertical instrument.**—This instrument may be summarily described as a transit, whose line of collimation moves in the plane of the prime vertical, instead of that of the meridian. Nevertheless, its astronomical uses are essentially distinct from those of the transit instrument (23).

The first instrument made on this principle was erected, in the beginning of the last century, under the direction of the celebrated Roemer, whose name is rendered memorable by the discovery of the mobility of light (542). It was applied by that astronomer chiefly to observations on the sun near the equinoxes; but none of the purposes to which it has more recently subserved appear to have been contemplated, and the instrument was allowed to fall into disuse. Its revival, and the idea of its application to various important classes of observations in the higher departments of practical astronomy, and more especially to replace the zenith sector in observations having for their object the more exact determination of aberration and nutation, and for researches in stellar parallax, is due to Professor Bessel. Many of the improved details of construction exhibited in the Pulkowa instrument are, however, due to Professor Struve, who, besides, has obtained such remarkable results by the system of observations which he has made with it.

The Pulkowa prime vertical instrument was constructed, under the direction of Professor Struve, by Messrs. Repsold, of Hamburg. Two stone piers being erected in planes at right angles to the me-

ridian, vertical chairs are fixed upon their summits in such a position that the line joining them is in the plane of the meridian. These chairs are the supports of the cylindrical extremities of the horizontal axis of the instrument, which is, therefore, also in the plane of the meridian. The extremities of this axis project beyond the chairs and the piers on each side, and the transit telescope is keyed on to one of them, while a counter-weight is keyed on to the other. The telescope, having its line of collimation adjusted at right angles to the horizontal axis, revolves with this axis outside the piers, in the same manner exactly as the transit telescope revolves between its piers; and as the line of collimation of the latter moves in the plane of the meridian, that of the transit telescope of the present instrument moves in the plane of the prime vertical.

Adjustments are provided in connection with the two chairs, one of which raises and lowers the axis, and the other moves it in azimuth, similar exactly to those described in the case of the transit instrument (25), *et seq.* By these means, and by proper levels, the axis is rendered truly horizontal, is brought exactly into the plane of the meridian, and the line of collimation is brought to coincide with the plane of the prime vertical by other expedients, similar in principle to those adopted in the case of the transit instrument.

The instrument, mounted on the piers, is represented in Plate VIII., as seen from the west, projected on the plane of the meridian, the telescope being on the north side, and placed so that the line of collimation is directed to the zenith. The telescope has 7 feet 7 inches focal length, with an object-glass having a clear aperture of 6·25 inches. The magnifying power commonly used is 270. In the eye-piece a system of seven parallel vertical micrometer wires is fixed, similarly to those of the transit instrument (22), and is similarly used with relation to the clock, as already described in the case of the latter instrument. A lamp is placed at a convenient distance from the centre of the telescope, the light of which, admitted by a plate of glass fixed in the side of the tube, is received upon a small reflector at 45° within, and reflected along the tube, so as to illuminate the wires at night.

To enable the observer to direct the telescope to any required altitude, a small telescope, called a *finder*, is fixed to the outside of the great telescope, near the eye-piece, having attached to it a graduated circle, the plane of which is parallel to the prime vertical, and also a level. The line of collimation of the finder being parallel to that of the great telescope, when the former is directed to any altitude by means of the level and graduated circle, the former will be similarly directed. This finder appears in the drawing

outside the telescope, and a counterpoise to it is represented on the inside.

The process of reversion of the horizontal axis, which in the transit instrument is only used for the purpose of adjustment (26), constitutes, in the case of the prime vertical instrument, an essential part of every observation. It was, therefore, of the greatest importance that an easy, expeditious, and safe apparatus for reversion should be provided. This was contrived with great ingenuity by the makers, and attended with the most successful results, results to which M. Struve ascribes a great share of the advantage obtained by this instrument. A part of this apparatus, by which the horizontal axis, with the telescope, counterpoise, and their accessories, is elevated from the chairs, is represented in the drawing above the instrument. The two cords of suspension being attached by hooks to two points on the axis at equal distances from its centre, so as to maintain the equilibrium, the instrument is elevated by means of a windlass established on the floor below it and between the piers. When raised to the necessary height, it is turned through half a revolution in azimuth, so that the ends of the axis are brought directly over the chairs, into which they are then let down. So perfect is the performance of this apparatus, that, notwithstanding the magnitude and weight of the instrument, the whole process of reversion is completed in sixteen seconds; and the interval, from the moment the observer completes an observation with the telescope on the north side, to the moment he commences it on the south side, including the time of rising from the observing-couch, disengaging the clamps, withdrawing the key from the micrometer, reversing, directing the instrument on the south side to the object by means of the finder, closing the clamps, returning the key to the micrometer, and placing himself on the observing-couch, is only 80 seconds.

How essential to the practical use of the instrument this celerity is, will be understood when it is stated, that the same object which has been observed on one side must be also observed on the other *in the same transit.* The reversion, therefore, must be completed in less time than that which the object takes by the diurnal motion to pass over the space commanded by the field of the telescope in the two positions.

To comprehend the method of applying this instrument to the purposes of practical observation, it is necessary to remember that it is only applicable to objects moving in parallels of declination which intersect the prime vertical. Such objects must have northern declination (the instrument being supposed to be established in a place having north latitude), and a polar distance greater than that of the zenith of the observatory, that is to say, greater

than its co-latitude. The parallels over which such objects are carried by the diurnal motion, all intersect the prime vertical at two points of equal altitude, one on the eastern, and the other on the western, quadrant of that circle. In passing from the east point of intersection to the west point, the object passes over the meridian, and it is evident that the moment of its meridional transit is precisely the middle of the interval between its two prime vertical transits. If, therefore, the exact times of the latter be observed, the time of the meridional transit can be deduced by a simple arithmetical process.

When the telescope, being on the north side, is directed and clamped in its position, the observer awaits the transit, the time of which he already knows approximately. At the near approach of the transit he places himself on the observing-couch, and, seeing the object enter the field, notes the seconds by the clock of its transits over the seven wires of the micrometer.

The moment the transit over the seventh wire has been observed he rises and performs all that is necessary for the reversion of the instrument, which being completed, he again places himself, and observes the transits over the seven wires on the south side; but in this case, owing to the change of position, the order of the transits is reversed.

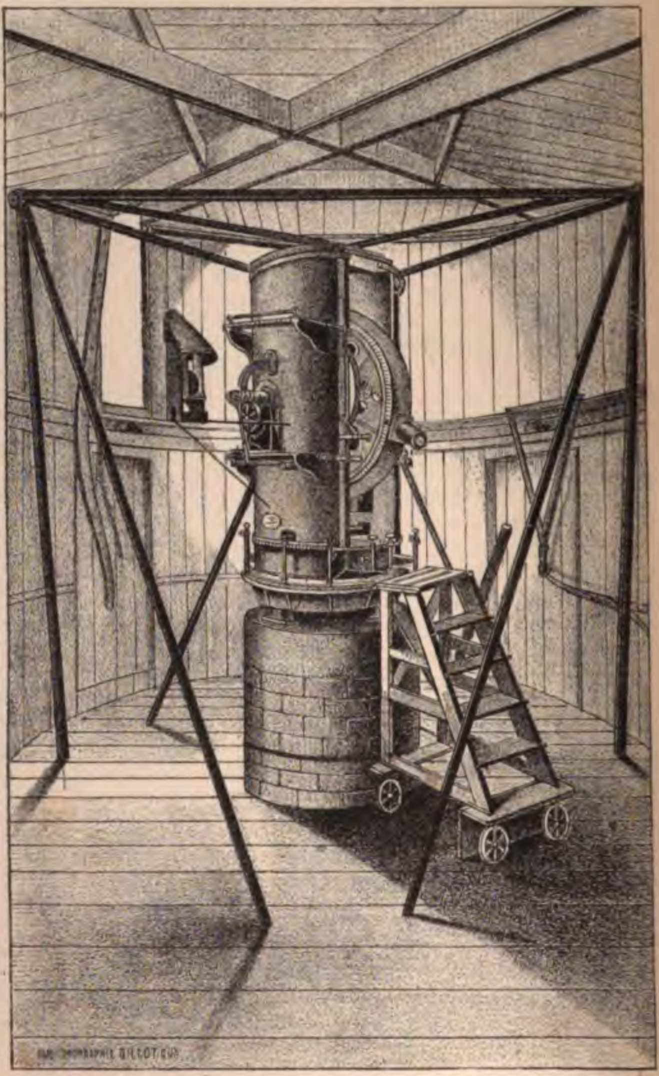
Now, it is evident that the true moment of the transit over the prime vertical will be found by taking a mean between the times of the transits over all the wires at both sides. These observations being completed, the observer awaits the transit of the object over the western quadrant of the prime vertical, when he makes a similar series of observations of transits, first with the telescope on the south side, in the position it had at the last observation, and then, after reversion, at the north side. The true moment of the transit is found, in this case, in the same manner as in the former.

By taking a mean of these two means, or, what would be equivalent, a mean of the times of all the twenty-eight transits, the time of the meridional transit will be obtained.

The total length of the interval, necessary to observe the transits over the wires, north and south, in each quadrant of the prime vertical, is found to be about eleven minutes, less than 1½ minute of which is employed in the reversion of the instrument and attendant arrangements.

The time which elapses between the observations on the eastern and western quadrants of the prime vertical, will necessarily vary with the polar distance of the object, and will be less in proportion as excess of that distance above the co-latitude is less. The observations which have been made with this instrument at Pulkowa have been chiefly confined to stars whose polar distance exceeds the

IX.



GREENWICH ALTAZIMUTH INSTRUMENT.

co-latitude by less than 2°. In that case, the interval between the observations, east and west, would be less than three hours.

Professor Struve notices, in strong terms, the advantage which this instrument possesses over others in respect to the errors arising from the variation of the inclination of the line of collimation to the axis of rotation. In the prime vertical instrument, the deviation of the line of collimation from true perpendicularity to the axis of rotation, is assumed to be invariable only during the short interval of a single observation, whereas, in other instruments, its invariability is assumed for twelve hours, and in some cases for months, and even years. It has the further great advantage, that, by reversion in each quadrant, east and west, all optical imperfections which affect the precision of the image of the star are absolutely annihilated.*

49. **The Greenwich altazimuth instrument.**—The purpose chiefly to which this instrument is applied, is the improvement of the lunar theory by multiplying in a large ratio the observations which can be made from month to month of the moon in almost every part of her orbit, thus supplying materials on an increased scale for a comparison of observed positions of the moon, with places calculated from tables formed for that purpose from theory. Similar observations were always made with the mural circle and the transit, but they were consequently confined to meridional transits. Now, these transits cannot be observed on the meridian, even when the firmament is unclouded, for four days before and four days after the new moon, in consequence of the proximity of that body to the sun; an interval amounting to little less than one-third of the month. Besides this, it happens, in this climate, that, at the moment of the meridional transits at other parts of the month, the observation is frequently rendered impracticable by a clouded sky. It was, therefore, highly desirable to contrive some means of making the observations in extra-meridional positions of the moon which would bear comparison with those made with the meridional instruments.

This could obviously be accomplished by means of an ordinary altitude and azimuth circle; but such an instrument, however perfect might be its construction, is not susceptible of the necessary precision. The Astronomer Royal, therefore, conceived the idea of an instrument on the same principle, which, while it would be capable of shifting its azimuth, would still be susceptible of as much precision in each vertical in which it might be placed, as the

* For a detailed account of the Pulkowa prime vertical instrument, see *Description de l'Observatoire Astronomique de Pulkowa*, par F. G. W. Struve. Also *Astronomische Nachrichten*, No. 468, *et seq.*

mural circle has in the meridian. He accordingly proposed to attain this object by adopting adequate engineering expedients to produce the necessary solidity and invariability of form. He adopted, as fundamental principles of construction,—

1. To produce as many parts as possible in a single casting;
2. To use no small screws for combining the parts;
3. To allow no power of adjustment anywhere.

Following out these principles, the instrument represented in Plate IX. was constructed, under his superintendence, by Messrs. Ransome and May, engineers, of Ipswich; the graduation and optical part being executed by Messrs. Troughton and Simms.

The instrument is mounted in a tower, raised to such a height as to command the horizon in all directions above the other buildings of the Observatory, except on the side of the south-east dome and the octagon room. The foundation of the instrument is a three-rayed pier of brickwork, carried up nearly to the level of the floor of the room appropriated to the instrument. Upon this pier is placed a cylindrical stone pillar, 3 feet in diameter, which appears in the drawing, and on which the instrument is placed. This pillar and the pier upon which it reposes are quite independent of, and unconnected with, the tower within which it is erected, and do not even touch the floor of the room through which they pass.

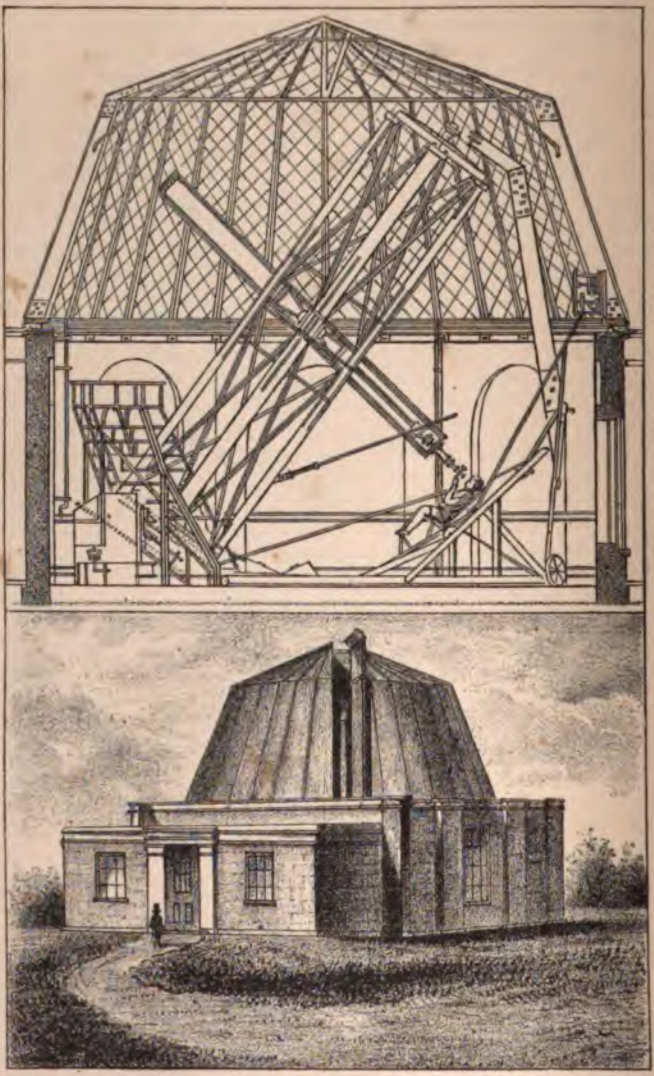
The fixed horizontal azimuth circle is solidly established upon this stone pillar. It is a circle 3 feet in diameter, the rim being connected with the centre in the usual way by spokes. The whole is constructed of hard gun-metal. In the upper surface of the rim a circular groove is left, which is filled with a band of silver, on which the divisions are engraved. This circle is divided into arcs of $5'$ continuously from $0°$ to $360°$. It is set with the zero towards the south, and the numbering of the divisions runs from south to west, north and east. This azimuthal circle was cast in a single piece, and weighs 441 lbs.

Attached to this, and concentric with it, is another fixed horizontal circle, having teeth on the inside edge, in which the pinions work by which an azimuth motion is given to the instrument.

There are four microscopes placed at equal distances over the graduated arc, which are provided with micrometers, by which the observation in azimuth is read off. These microscopes are attached to the instrument so as to revolve with it. Their reflectors are illuminated by a lamp properly placed.

The lower pivot on which the instrument turns is spherical, and takes a bearing upwards in a socket in the base-plate, and downwards in a cone of hard gun metal. A portion of the weight of

X.



NORTHUMBERLAND EQUATORIAL.

CAMBRIDGE OBSERVATORY.

the instrument is taken off by a counterpoise acting by levers which push a slider upwards against the pivot. To support the upper pivot, an iron triangle is established on the three-rayed pier. On each side of this, is erected another iron triangle, whose plane is vertical, and whose sides unite in a vertex which forms one of the angles of a corresponding triangle above. This upper triangle supports three radial bars, which carry at their point of union the Y in which the upper pivot plays. The bars of the lateral triangles, which are apparent in the drawings, pass the holes in the floor without touching it.

The frame, revolving in azimuth and carrying the instrument with it, consists of a top and bottom connected by vertical cheeks, all of cast-iron. The supports of the four microscopes for reading off the azimuth on the lower circle are cast in the same piece with these vertical cheeks.

The vertical circle carrying the telescope is 3 feet in diameter, and, like the azimuth circle, is made of hard gun metal. The aperture of the object-glass is $3\frac{3}{4}$ in. The top and bottom of the instrument each carries two levels, parallel to the plane of the horizontal axis, used in observations of azimuth; and two levels are fixed on one of the vertical cheeks parallel to the plane of the vertical circle, used in observations of zenith distance.

The dome over the instrument is cylindrical, with double sides, between which the air passes freely. Its diameter is 10 feet.

The drawing represents the instrument as in use. The ladder revolves in azimuth, round the central pier, — to facilitate which motion, rollers are placed under it. A metal frame is attached to the vertical cheek of the instrument, having its edges in a plane parallel to that of the vertical circle. The eye being directed along these to view the object, the instrument is placed very nearly in the proper azimuth, and the telescope is then accurately directed to the object by the ring-finder. This frame is omitted in the drawing.

The results of the observations made with this instrument are stated to have fulfilled all the anticipations of the Astronomer Royal, as well as to the number of observations as to their excellence. The number of observations have exceeded those made with the meridional instruments in the proportion of about 16 to 9. Some have been made even within a day of conjunction.

50. **The Northumberland equatorial — Cambridge Observatory.** — The late Duke of Northumberland, who filled during the latter part of his life the high and honourable office of Chancellor of the University of Cambridge, presented to that university this instrument, which, successively in the hands of the Astronomer Royal and Professor Challis, has contributed so effectually to the advancement of astronomical science.

The instrument, of which a perspective view is given in Plate X., together with a view of the building in which it is erected, consists of a refracting telescope of 19½ feet focal length and 11½ inches aperture equatorially mounted. The polar axis, as appears in the drawing, consists of a system of framing composed of six strong deal poles, attached at the ends to two hexagonal frames of cast-iron, the centres of which support the upper and lower pivots on which the telescope revolves. These poles at the middle are braced by transverse iron bands, and by a system of diagonal rods of deal abutting near the middle of the poles. These give stiffness to the entire framing of the polar axis, and maintain the hexagonal frames square to it. Efficient means are provided to give elasticity to the supports of the pivots and smoothness to the equatorial motion.

The tube of the telescope is made of well-seasoned deal, and attached to one side of it is a flat brass bar, 6 feet long, carrying a small graduated arc at right angles to it at one end, and turning at the other on a pin fixed in the telescope tube at a distance of 30 inches from the axis of revolution. This arc, which is called the declination sector, serves to measure small differences of declination, and is read by a micrometer microscope fixed to the telescope tube.

The hour-circle, which measures the equatorial motion, is 5½ feet in diameter, and is so arranged that it can be clamped to the telescope, or disengaged from it, at pleasure. It has two indices with verniers, one fixed to the support of the lower pivot, and the other to the hexagonal frame. By setting the latter to a certain angle, determined by an observation of a star of known right ascension, the telescope can be directed to any proposed right ascension by means of the other index. Observations of right ascension can be made to 1 second of time. The outer rim of the circle is cut into teeth, which are acted on by an endless screw connected at pleasure by a brass rod with a large clock, by which a motion can be given to the telescope corresponding with the diurnal motion of the heavens.

The hour-circle is clamped to the frame of the axis by a tangent-screw-clamp fixed to the frame itself, by means of which, with the aid of a handle extending to the place of the observer, he can, when the endless screw is applied, give motion to the instrument through a limited space upon the hour-circle. The rate of motion given to the hour-circle by the clock is not affected by this movement. The hour-circle, therefore, going according to sidereal time, small differences of right ascension can be measured by reading off the angles pointed to by the movable index before and after the changes of position.

The dome which covers the instrument, and which, as well as the other details of its erection, was constructed under the direction

of the Astronomer Royal, who was then the Cambridge astronomer, is supported so as to revolve on free balls between concave channels, holdfasts of peculiar construction being provided to obviate the eventuality of the dome being dislodged or blown off by wind or any other unusual disturbance. The winch which acts on the machinery for turning the dome, is carried to the observer's chair, so that he can, while engaged in a long observation, turn the dome slowly without removing from his position.

The magnitude of the instrument, and the consequent extensive motion of the eye-piece, rendered it necessary to contrive adequate means by which the observer could be carried with the eye-piece by a common motion without any personal derangement which might disturb the observation. This is accomplished by means of an ingenious apparatus consisting of a frame, of which the upper edge is nearly a circular arc whose centre is the centre of the telescope, which frame traverses horizontally round a pin in the floor exactly below the centre of the telescope, the observer's chair sliding on the frame. The observer can, by means of a winch placed beside his chair, turn round the frame on which the chair is supported, and by means of a lever and ratchet wheel he can raise and lower the chair on the frame. He has also means of raising and depressing the back of the chair so as to give it the inclination he may at the moment find most convenient.

51. **The Greenwich great equatorial.**—This instrument, which was completed in the beginning of the year 1860, was erected from designs by the Astronomer Royal, by Messrs. Ransomes and Co. of Ipswich, the general optical work being performed by Messrs. Troughton and Simms, of London. It consists of a telescope with an object-glass by Merz of 12¾ inches aperture, and about 18 feet focal length, mounted according to the principle, known as the English form of equatorial mounting.

No novelty is introduced into the construction of the polar axis, except that the declination axis is so far advanced in front of the polar axis, and the upper part of the polar frame is so cut away that the telescope commands the meridian without interruption to a short distance beyond the pole. Each cheek of the polar axis is constructed in the form of a skeleton prism, the pillars being braced by a series of diagonal tension bars and transversal thrusting bars; these are of wrought iron. The upper and lower ovals which carry these are of cast iron. On the spindle of the lower oval, the hour-wheel, 6 feet in diameter, on which the clock movement acts, turns freely; this wheel can be clamped when necessary to the oval or to the foundation-plate.

The declination circle, attached to the declination axis, is read by two microscopes placed in such a position, that though they

view opposite graduations on a 5-feet circle, the eye-pieces are only a few inches apart. For the illumination of the microscopes the light enters a hole in the side of the eye-tube, when it is reflected downwards by diagonal plates of transparent glass; it then falls upon the limb, whose surface is turned to a concave or dished conical form, so that the axis of the microscope is perpendicular to the portion of the limb under view; the light, therefore, which has been thrown down that axis is again reflected up the axis to the eye. There is a 5-feet clamp circle attached to the opposite cheek of the polar axis, whose clamp-screw and slow-motion are acted on by long handles near the eye end of the telescope.

For convenience of setting, and for reading small differences of polar distances, a radial bar is fixed on one side of the telescope, which turns on a pin near the centre of motion, its graduation being near the eye end of the telescope; this radial bar is bridled by a graduated sliding rod, of which the distant end is carried by a pin on one cheek of the polar axis.

The instrument is provided with a clock movement, which is a beautiful specimen of the application of mechanism for driving smoothly so heavy a mass. From a self-supplying tank placed on the upper story of the building, a sufficient fall of water is obtained for working a reaction machine, which revolves four times in a second. This, acting through two worms, drives the hour-circle. The regulation is effected by the contrivance called Sieman's chronometric governor, acting upon a pendulum having an uniform conical motion.

The limits of this work do not permit a lengthened detail of all the peculiarities of this instrument, especially as, in many respects, the general appearance and many of its parts are very similar to what is already described in the account of the Northumberland equatorial. However, as a specimen of astronomical engineering it is considered unique; and the adoption in its construction of every modern instrumental improvement, together with its great stability, renders it one of the most important instruments of its class to be found in any country.

CHAPTER III.

THE GENERAL ROTUNDITY AND DIMENSIONS OF THE EARTH.

52. **The earth a station from which the universe is observed.**—The earth is, in various points of view, an interesting object of scientific investigation. The naturalist regards it as the habitation of the numerous tribes of organised beings which are

the special subject of his observation and inquiry, and examines curiously those properties and qualities of soil, climate and atmosphere, by which it is fitted for their maintenance and propagation, and the conditions which govern their distribution over its surface. The geologist and mineralogist regard it as the theatre of vast physical operations continued through periods of time extending infinitely beyond the records of human history, the results of which are seen in the state of its crust. The astronomer, rising above these details, regards it as a whole, examines its form, investigates its motions, measures its magnitude, and, above all, considers it as the station from which alone he can take a survey of that universe which forms the peculiar object of his study, and as the only modulus or standard by which the magnitudes of all the other bodies in the universe, and the distances which separate them from the earth and from each other, can be measured.

53. **Necessary to ascertain its form, dimensions, and motions.**—But since the apparent magnitudes, motions, and relative arrangement of surrounding objects severally vary, not only with every change in the position of the station of the observer, but even with every change of position of the observer on that station, it is most necessary to ascertain with all attainable accuracy the dimensions of the earth, which is the station of the astronomical observer, its form, and the changes of position in relation to surrounding objects to which it is subject.

54. **Form globular.**—The first impression produced by the aspect presented by the surface of the earth is that of a vast indefinite plane surface, broken only by the accidents of the ground on land, such as hills and mountains, and by the more mutable forms due to the agitation of the fluid mass on the sea. Even this departure from the appearance of an extensive plane surface ceases on the sea out of sight of land in a perfect calm, and on certain plains of vast extent on land, such as some of the prairies of the American continents.

This first impression is soon shown to be fallacious; and it is easily demonstrated that the immediate indications of the unaided sense of vision, such as they are, are loosely and incorrectly interpreted, and that, in fact, even that small part of the earth's surface which falls at once within the range of the eye in a fixed position *does not appear to be a plane.*

Supposing that any extensive part of the surface of the earth were really a plane, let several stakes or posts, of equal height, be erected along the same straight line, and at equal distances, say a mile apart. Let these stakes be represented by S *s*, S′ *s*′, S″ *s*″, &c., *fig.* 16, and let a stake of equal height, O *o*, be erected at the station of the observer. Now if the surface were a plane, it is evident that

the points s, s', s'', &c. must appear to an eye placed at o in the same visual line, and would each be visible through a tube directed

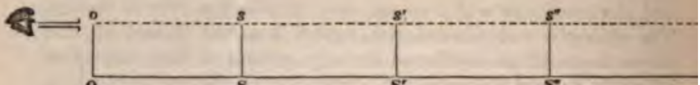


Fig. 16.

at o parallel to the surface O S. But such will not be found to be the case. When the tube is directed to s, all the succeeding points s', s'', &c. will be *below* its direction. If it be directed to s', the point s will be *above*, and s'' and all the succeeding points will be *below* its direction. In like manner, if it be directed to s'', the preceding points s and s' will be *above*, and the succeeding points *below* its direction. In effect it will appear as though each succeeding stake were a little shorter than the preceding one. But as the stakes are all precisely equal, it must be inferred that the successive points of the surface S, S′, S″, S‴, &c. are relatively lower than the station O. Nor will the effects be explained by the supposition that the surface O S S′ S″, &c., is a descending but still a *plane* surface, because in that case the points s, s', s'', &c. must still be in the same visual line directed from o. It therefore follows

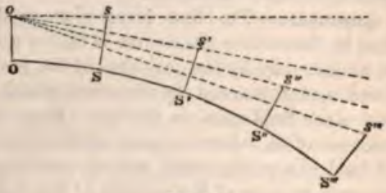


Fig. 17.

that the surface in the direction O S S′ S″ S‴, &c. is not *plane* but *curved*, as represented in *fig.* 17, where the visual lines are in obvious accordance with the actual appearances as above explained.

Now since these effects are found to prevail in every direction around the point of observation O, it follows that the curvature of the surface prevails all around that point; and since the *extent of the depression* of the points S, S′, S″, &c. at equal distances from O, are equal in every direction around O, it follows that the curvature is in every direction sensibly uniform around that point.

But by shifting the centre of observation O, and making similar observations elsewhere, and on every part of the earth where such a process is practicable, not only are like effects observed, but the

degree of depression corresponding to equal distances from the centres of observation is the same.

Hence we infer that the surface of the earth, *as observed directly by the eye*, is not a plane surface, but one everywhere curved, and that the curvature is everywhere uniform, at least that no departure from perfect uniformity in its general curvature exists sufficiently considerable to be discovered by this method.

But the only form of a solid body which has a surface of uniform curvature is a sphere or globe, and it is therefore established that such is the form of the earth.

55. **This conclusion corroborated by circumnavigation.**—If a vessel sail, as far as it is practicable to do so, constantly in the same direction, it will at length return to the port of its departure, having circumnavigated the earth, and during its course it appears to pass over an uniform surface. This is obviously what must take place so far as regards that part of the earth which is covered with water, supposing it to be a globe.

56. **Corroborated by lunar eclipses.**—But the most striking and conclusive corroboration of the inference just made, and indeed a phenomenon which alone would demonstrate the form of the earth, is that which is exhibited in lunar eclipses. These appearances, which are so frequently witnessed, are caused by the earth coming between the sun and the moon, so as to cast its shadow upon the latter. Now the form of that shadow is *always* precisely that which *one globe would project upon another*. The phenomenon thus at once establishes not only the globular form of the earth, but that of the moon also.

57. **Various effects indicating the earth's rotundity.**—The rotundity of the earth being once admitted, a multitude of its consequences and effects present themselves, which supply corroborative evidence of that important proposition.

When a ship sails from the observer, the first part which should cease to be visible, if the earth were a plane, would be the rod of the

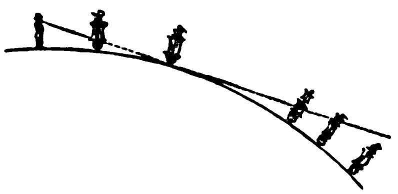


Fig. 18.

top-mast, having the smallest dimensions, and the last the hull and sails, being the greatest in magnitude;—but, in fact, the very

reverse takes place. The hull first disappears, then the sails, and lastly the top-mast alone is visible by a telescope, appearing like a pole planted in the water. This becomes gradually shorter, appearing to sink in the water as the vessel recedes from the eye.

These appearances are the obvious consequences of the gradual interposition of the convexity of the part of the earth's surface over which the vessel has passed, and will be readily comprehended by the *fig.* 18.

If the observer take a more elevated position, the same succession of phenomena will be presented, only greater distances will be necessary to produce the same degree of apparent sinking of the vessel.

Fig. 19.

Land is visible from the top-mast in approaching the shore, when it cannot be seen from the deck.

The top of the peak of Teneriffe can be seen from a distance when the base of the mountain is invisible.

The sun shines on the summits of the Alps long after sunset in the valleys.

An aeronaut ascending after sunset has witnessed the sun reappear with all the effects of sunrise. On descending, he witnessed a second sunset.

58. **Dimensions of the earth.—Method of measuring a degree.**—Having thus ascertained that the form of the earth is a globe, it now remains to discover its magnitude, or, what is the same, its diameter.

For this purpose it will be necessary first to ascertain the actual length of a degree upon its surface, that is, the distance between two points on the surface, so placed that the lines drawn from them to the centre shall make with each other an angle of one degree.

Let p and p', *fig.* 19, represent two places upon the earth's surface, distant from each other from 60 to 100 miles, and let c be the centre of the earth. Now, let us suppose that two observers at the places p and p' observe two stars s and s', which at the same time are vertically over the two places, and to which, therefore, plumb-lines suspended at the two places would be directed. The direction of these plumb-lines, if continued downwards, would intersect at C, the centre of the earth. The visual angle under the directions of these stars s and s' at p'

is $s\,p\,s'$, and at C is $s\,\mathrm{C}\,s'$. But, owing to the insignificant proportion which the distances $p\,p'$ and $p\,\mathrm{C}$ bear to the distances of the stars, the visual angle of the stars, whether seen from p or C, will be the same. If, then, this visual angle at p' be measured, as it may be with the greatest precision, we may consider it as the magnitude of the angle $p\,\mathrm{C}\,p'$.

Let the actual distance D, between the places p and p', be measured or ascertained by the process of surveying, and the number of seconds in the observed angle $s\,p'\,s'$ be expressed by a. If d express the distance of two points on the earth which would subtend at the centre C an angle of 1°, we shall then have—

$$a : 3600 :: \mathrm{D} : d = \mathrm{D} \times \frac{3600}{a},$$

since the number of seconds in a degree is 3600.

59. **Length of a degree.**—In this way it has been ascertained that the length of a degree of the earth's surface is a little less than 70 British statute miles, and may be expressed in feet (in round numbers) by 365,000.

It will therefore be easy to remember that the length of a degree is as many thousand feet as there are days in the year.

60. **Length of a second of the earth.—To find the earth's diameter.**—Since a second is the 3600th part of a degree, it follows also that the length of a second is a hundred feet very nearly, a measure also easily remembered

Nothing can be more easy, after what has been stated, than the solution of the problem to determine the earth's diameter. If r express the radius or semidiameter of the earth C p, a the arc $p\,p'$ of the earth's surface between the two places, *fig.* 19, and α the angle $p\,\mathrm{C}\,p'$, we shall have

$$r = a \times \frac{206,265}{\alpha''}.$$

If the distance a be one degree, this will become

$$r = \frac{365,000}{3,600} \times 206,265 = 20,912,979,$$

or very nearly twenty-one million feet, which is equal to 3960 statute miles. So that the diameter of the earth would be 7920 miles, or in round numbers (for we are not here pretending to extreme arithmetical precision) about 8000 miles.

The process of observation above explained is not in its details exactly that by which the magnitude of the earth is ascertained, but it is in spirit and principle the method of observation and calculation. It would not be easy to find, for example, any two

observable stars which at one and the same moment would be vertically over the two places p and p', but any two stars nearly over them would equally answer the purpose by observing the extent of their departure from the vertical direction. Neither is it necessary that the two observations should exactly coincide as to time; but these details do not affect the principle of the method, though they require some consideration to make them clearly intelligible.

61. **Superficial inequalities of the earth relatively insignificant.** — It is by comparison alone that we can acquire any clear or definite notions of distances and magnitudes which do not come under the immediate cognizance of the senses. If we desire to acquire a notion of a vast distance over which we cannot pass, we compare it with one with which we have immediate and actual acquaintance, such as a foot, a yard, or a mile. In Astronomy, having to deal with magnitudes exceeding in enormous proportions those of all objects, even the most stupendous, which are so approachable as to afford means of direct sensible observation, we are incessantly obliged to have recourse to such comparisons in order to give some degree of clearness to our ideas, since without them our knowledge would become a mere assemblage of words, numbers, and geometrical diagrams.

When it is stated that the earth is a globe, the first objection which will be raised by the uninformed student is that the continents, islands, and tracts of land with which it is covered are marked by considerable inequalities of level; that mountains rise into ridges and peaks of vast height; that the seas and oceans, though level at their surface in a certain general sense, are agitated by great waves, and alternately swelled and depressed by tides, and that the solid bottom of them is known to be subject to inequalities analogous in character, and not less in depth, than those which prevail on the land. Since, then, it is the characteristic property of a globe that all points on its surface are equally distant from its centre, how, it may be demanded, can a mass of matter, so unequal in its surface as the earth is, be a globe?

It may be conceded at once, in reply to this objection, that the earth is not, in the strict geometric sense of the term, a globe. But let us consider the extent of its departure from the globular form, so far as relates to the superficial inequalities just adverted to.

The most lofty mountain peaks do not exceed five miles in height. Few, indeed, approach that limit. Most of the considerable mountainous districts are limited to less than half that height. No considerable tract of land has a general elevation even of one mile. The deepest parts of the sea have not been sounded; but it is certain that their depth does not exceed the heights of the most

lofty mountains, and the general depth is incomparably less. The superficial inequalities of the aqueous surface produced by waves and tides are comparatively insignificant.

Now, let us consider how these several superficial inequalities would be represented, observing a due proportion of scale, even on the most stupendous model.

Construct a globe 20 feet in diameter, as a model of the earth. Since 20 feet represents 8000 miles, 1-400th part of a foot, or 3-100th parts of an inch, represents a mile. The height, therefore, of the most lofty mountain peak, and the greatest depth of the ocean, would be represented by a protuberance or a hole having no greater elevation or depth than 15-100ths, or about the seventh part of an inch. The general elevation of a continent would be fairly represented by a leaf of paper pasted upon the surface, having the thickness of less than the fiftieth of an inch; and a depression of little greater amount would express the depth of the general bed of the sea.

It will therefore be apparent, that the departure of such a model from the true form of a globe would be in all, save a strictly geometrical sense, absolutely insignificant.

62. **Relative dimensions of the atmosphere.**—The surface of the earth is covered by an ocean of air which floats upon it, as the waters of the seas rest upon their solid bed. The density of this fluid is greatest in the stratum which is in immediate contact with the surface of the land and water of the earth, and it diminishes in a very rapid ratio in ascending, so that one half of the entire atmosphere is included in the strata whose height is within $3\frac{1}{2}$ miles of the surface. At an altitude of 80 miles, or the hundredth part of the earth's diameter, the rarefaction must be so extreme, that neither animal life nor combustion could be maintained.

The atmosphere, being then limited to such a height, would be represented on the model above described by a stratum two inches and a half thick.

63. **If the earth moved, how could its motion be perceived?**—Nothing is more repugnant to the first impressions received from the aspect of the surface of the earth, and all upon it, than the idea that it is in motion. But if this universal impression be traced to its origin, and rightly interpreted, it will not be found erroneous, and will form no exception to the general maxim which induces all persons, not even excepting philosophers, to regard without disrespect notions which have obtained universal popular acceptation.

What is the stability and repose ascribed by the popular judgment to the earth? Repose certainly absolute, so far as regards all

objects of vulgar or popular contemplation. It is maintained, and maintained truly, that everything upon the earth, so far as the agency of external causes is concerned, is at relative rest. Hills, mountains, and valleys, oceans, seas, and rivers, as well as all artificial structures, are in relative repose; and if our observation did not extend to objects exterior to the globe, the popular maxim would be indisputable. But the astronomer contemplates objects which either escape the attention of, or are imperfectly known to mankind in general; and the phenomena which attend these render it manifest, that while the earth, in relation to all objects upon it and forming part of it, is at rest, it is in motion with relation to all the other bodies of the universe.

The motion of objects external to the observer is perceived by the sense of sight only, and is manifested by the relative displacement it produces among the objects affected by it, with relation to objects around them which are not in motion, and with relation to each other. Motions in which the person of the observer participates may affect the senses both of feeling and sight. The feeling is affected by the agitation to which the body of the observer is exposed. Thus, in a carriage which starts or stops, or suddenly increases or slackens its speed, the matter composing the person of the observer has a tendency to retain the motion which it had previous to the change, and is accordingly affected with a certain force, as if it were pushed or drawn from rest in one direction or the other. But once in a state of uniform motion, the sense of feeling is only affected by the agitation proceeding from the inequalities of the road. If these inequalities are totally removed, as they are in a boat drawn at a uniform rate on a canal, the sense of feeling no longer affords any evidence whatever of the motion.

A remarkable example of the absence of all consciousness of motion, so far as mere feeling is concerned, is presented to all who have ascended in a balloon. As the aerial vehicle floats with the stratum of the air in which it is suspended, the feeling of the aeronaut is that of the most absolute repose. The balloon seems as fixed and immovable as the solid globe itself, and nothing could produce in the voyager, blindfolded, any consciousness whatever of motion. When however his eyes, unbandaged, are turned downwards, he sees the vast diorama below moving under him. Fields and woods, villages and towns pass in succession, and the phenomena are such as to impress on the eye, and through the eye upon the mind, the conviction that the balloon is stationary, and the earth moving under it. A certain effort of the understanding, slight, it is true, but still an effort, is required to arrive at the inference that the impression thus produced on the sense of vision is an illusion, that the motion with which the landscape seems to be

affected is one which in reality affects the balloon in which the spectator is suspended, and that this motion is equal in speed, and contrary in direction, to that which appears to affect the subjacent country.

Now it will be evident, that if the globe of the earth, and all upon it, were floating in space, and moving in any direction at any uniform rate, no consciousness of such motion could affect any sensitive being upon it. All objects partaking in common in such motion, no more derangement among them would ensue than among the persons and objects transported in the car of the balloon, where the aeronaut, no matter what be the speed of the motion, can fill a glass to the brim as easily as if he were upon the solid ground. Supposing, then, that the earth were affected by any motion in which all objects upon it, including the waters of the ocean, the atmosphere, and clouds, would all participate, would the existence of such a motion be perceived by a spectator placed upon the earth who would himself partake of it? It is clear that he must remain for ever unconscious of it, unless he could find within the range of his vision some objects which, not partaking of the motion, would appear to have a motion contrary to that which the observer has in common with the earth.

But such objects are only to be looked for in the regions of space beyond the limits of the atmosphere. We find them in the sun, the moon, the stars, and all the objects which the firmament presents. Whatever motion the earth may have will impart to all these distant objects the appearance of a motion in the contrary direction.

CHAPTER IV.

SPHEROIDAL FORM, MASS, AND DENSITY OF THE EARTH.

64. **Progress of physical investigation approximative.** — It is the condition of man, and probably of all other finite intelligences, to arrive at the possession of knowledge by the slow and laborious process of a sort of system of trial and error. The first conclusions to which, in physical enquiries, observation conducts us, are never better than very rough approximations to the truth. These being submitted to subsequent comparison with the originals, undergo a first series of corrections, the more prominent and conspicuous departures from conformity being removed. A second approximation, but still only an approximation, is thus obtained; and another and still more severe comparison with the phenomena under investigation is made, and another order of corrections is

effected, and a closer approximation obtained. Nor does this progressive approach to perfect exactitude appear to have any limit. The best results of our intellectual labours are still only close resemblances to truth, the absolute perfection of which is probably reserved for a higher intellectual state.

The labours of the physical inquirer resemble those of the sculptor, whose first efforts produce from the block of marble a rude and uncouth resemblance of the human form, which only approaches the grace and beauty of nature by comparing it incessantly and indefatigably with the original; detaching from it first the grosser and rougher protuberances, and subsequently reducing its parts by the nicer and more delicate touches of the chisel to near conformity with the model.

It would however be a great mistake to depreciate on this account the results of our first efforts in the acquisition of a knowledge of the laws of nature. If the first conclusions at which we arrive are erroneous, they are not therefore the less necessary to the ultimate attainment of more exact knowledge. They prove, on the contrary, not only to be powerful agents in the discovery of those corrections to which they are themselves to be submitted, but to be quite indispensable to our progress in the work of investigation and discovery.

These observations will be illustrated by the process of instruction and discovery in every department of physical science, but in none so frequently and so forcibly as in that which now occupies us.

65. **Figure of the earth an example of this.** — The first conclusions at which we have arrived respecting the form of the earth is that it is a globe; and with respect to its motion is, that it is in uniform rotation round one of its diameters, making one complete revolution in twenty-four hours sidereal time, or $23^h\ 56^m\ 4^s{\cdot}09$ common or civil time.

66. **Globular figure incompatible with rotation.** — The first question then which presents itself is, whether this form and rotation are compatible? It is not difficult to show, by the most simple principles of physics, that they are not; that with such a form such a rotation could not be maintained, and that with such a rotation such a form could not permanently continue. And if this can be certainly established, it will be necessary to retrace our steps, to submit our former conclusions to more rigorous comparison with the objects and phenomena from which they were derived, and ascertain which of them is inexact, and what is the modification and correction to which it must be submitted in order to be brought into harmony with the other.

67. **Rotation cannot be modified — supposed form may.** — The conclusion that the earth revolves on its axis with a motion

corresponding to the apparent rotation of the firmament, is one which admits of no modification, and must from its nature be either absolutely admitted or absolutely rejected. The globular form imputed to the earth, however, has been inferred for observations of a general nature, unattended by any conditions of exact measurement, and which would be equally compatible with innumerable forms, departing to a very considerable and measurable extent from that of an exact geometrical sphere or globe.

68. **How rotation would affect the superficial gravity on a globe.**—Let N Q S, *fig* 20., represent a section of a globe supposed to have a motion of rotation round the diameter N S as an axis. Every point on its surface, such as P or P′, will revolve in a circle, the centre of which *o* or *o′* will beupon the axis, and the radius *o* P or *o′* P′ will gradually decrease in approaching the poles N and S, where no motion takes place, and will gradually increase in approaching the equator Q O Q, where the circle of rotation will be the equator itself.

Fig. 20.

A body placed at any part of the surface, such as P, being thus carried round in a circle, will be affected by a centrifugal force, the intensity of which will be expressed by (M. 314)

$$C = 1{\cdot}227 \times R \times N^2 \times W,$$

where $R = P\,o$, the radius of the circle, N the fraction of a revolution made in one second, and W the weight of the body, and the direction of which is P *c*.

This centrifugal force being expressed by P *c* is equivalent(M. 166), to two forces expressed in intensity and direction by P *m* and P *n*. The component P *m* is directly opposed to the weight W of the body, which acts in the line P O directed to the centre, and has the effect of diminishing it. The component P *n* being directed towards the equator Q, has a tendency to cause the body to move towards the equator; and the body, if free, would necessarily so move.

Now it will be evident, by the mere inspection of the diagram, that the nearer the point P is to the equator Q, the more directly will the centrifugal force P *c* be opposed to the weight, and consequently the greater will be that component of it, P *m*, which will have the effect of diminishing the weight.

But this diminution of the weight is further augmented by the increase of the actual intensity of the centrifugal force itself in

approaching the equator. By the above formula, it appears that the intensity of the centrifugal force must increase in proportion as the radius R or P *o* increases. Now it is apparent that P *o* increases gradually in going from P to Q, since P′ *o*′ is greater, and Q O greater still than P *o*; and that, on the other hand, it decreases in going from P to N or S, where it becomes nothing.

Thus the effect of the centrifugal force in diminishing weight being nothing at the pole N or S, gradually increases in approaching the equator; *first*, because its absolute intensity gradually increases; and *secondly*, because it is more and more directly opposed to gravity until we arrive at the equator itself, where its intensity is greatest, and where it is directly opposed to gravity.

The effects, therefore, produced by the rotation of a globe, such as the earth has been assumed to be, are — 1st. The decrease of the weights of bodies upon its surface, in going from the pole to the equator; and 2ndly, A tendency of all such bodies as are free, to move from higher latitudes in either hemisphere towards the equator.

69. **The figure must be some sort of oblate spheroid.** — Now the effects produced by centrifugal force caused by the rotation of the earth, would be fulfilled if, instead of being an exact sphere, it were an oblate spheroid, having a certain definite ellipticity, — that is, a figure which would be produced by an ellipse revolving round its shorter axis. Such a figure would resemble an orange or a turnip. It would be more convex at the equator than at the poles. A globe composed of elastic materials would be reduced to such a figure by pressing its poles together so as to flatten more or less the surface of these points, and produce a protuberance around the equator. The meridians of such a globe would be ellipses, having its axis as their lesser axis, and the diameters of the equator as their greater axes.

Fig. 21.

The form of the meridian would be such as is represented in *fig.* 21, N S being the axis of rotation, and Æ Q the equatorial diameter.

70. **Its ellipticity must depend on gravity and centrifugal force.** — The protuberance around the equator may be more or less, according to the ellipticity of the spheroid; but since the distribution of land and water is indifferent on the surface, having no prevalence about the equator rather than about the poles, or *vice versâ*, it is evident that the degree of protuberance must be that which counteracts, and no more than counteracts, the tendency of the fluids, in virtue of the centrifugal force, to flow towards the

equator. This protuberance may be considered as equivalent in its effects to an acclivity of regulated inclination, rising from each pole towards the equator. To arrive at the equator the fluid must ascend this acclivity, to which ascent gravity opposes itself, with a force depending on its steepness, which increases with the magnitude of the protuberance, or, what is the same, with the ellipticity of the spheroid. If the ellipticity be less than is necessary to counteract the effect of the centrifugal force, the fluid will still flow to the equator, and the earth would consist, as before, of a great equatorial ocean separating two vast polar continents. If the ellipticity were greater than is necessary to counteract the effect of the centrifugal force, then gravity would prevail over the centrifugal force, and the waters would flow down the acclivities of the excessive protuberance towards the poles, and the earth would consist of a vast equatorial continent separating two polar oceans.

Since the geographical condition of the surface of the earth is not consistent with either of these consequences, it is evident that its figure must be an oblate spheroid, having an ellipticity exactly corresponding to the variation of gravity upon its surface, due to the combined effect of the attraction exerted by its constituent parts upon bodies placed on its surface, and the centrifugal force arising from its diurnal rotation.

It remains, therefore, to determine what this particular degree of ellipticity is, or, what is the same, to determine by what fraction of its whole length the equatorial diameter Æ Q exceeds the polar axis N S.

71. **Ellipticity may be calculated and measured, and the results compared.** — The degree of ellipticity of the terrestrial spheroid may be found by theory, or ascertained by observation and measurement, or by both these methods, in which case the accordance or discrepancy of the results will either prove the validity of the reasoning on which the theoretical calculation is founded, or indicate the conditions or data in such reasoning which must be modified.

Both these methods have accordingly been adopted, and their results are found to be in complete harmony.

72. **Ellipticity calculated.** — The several quantities which are involved in this problem are: —

1. The time of rotation = R.
2. The fraction of its whole length by which the equatorial exceeds the polar diameter = e.
3. The fraction of its whole weight by which the weight of a body at the pole exceeds the weight of the same body at the equator = w.
4. The mean density of the earth.

5. The law according to which the density of the strata varies in proceeding from the surface to the centre.

All these quantities have such a mutual dependence, that when some of them are given or known, the others may be found.

In whatever way the solution of the problem may be approached, it is evident that the form of the spheroid must be the same as it would be if the entire mass of the earth were fluid. If this were not so, the parts actually fluid would not be found, as they are always, in local equilibrium. The state of relative density of the strata proceeding from the surface to the centre is, however, not so evident. Newton investigated the question by ascertaining the form which the earth would assume if it consisted of fluid matter of uniform density from the surface to the centre; and the result of his analysis was that, in that case, assuming the time of rotation to be what it is, the equatorial diameter must exceed the polar by the 230th part of its whole length, and gravity at the pole must exceed gravity at the equator by the same fraction of its entire force.

As physical science progressed, and mathematical analysis was brought to a greater state of perfection, the same problem was investigated by Clairault and several other mathematicians, under more rigorous conditions. The uniform density of the constituents of the earth — a highly improbable supposition — was put aside, and it was assumed that the successive strata from the centre to the surface increased in density according to some undetermined conditions. It was assumed that the mutual attraction of all the constituent parts upon any one part, and the effect of the centrifugal force arising from the rotation, are in equilibrium; so that every particle composing the spheroid, from its centre to its surface, is in repose, and would remain so were it free to move.

By a complicated and very abstruse, but perfectly clear and certain mathematical analysis, it has been proved that the quantities above mentioned have the following relation. Let r express a certain number, the amount of which will vary with R. We shall then have

$$e + w = r.$$

Now it has been shown that when $\text{R} = 23^{\text{h}}\ 56^{\text{m}}\ 4^{\text{s}}{\cdot}09$, the number r will be $\frac{1}{115}$, so that in effect

$$e + w = \frac{1}{115}.$$

This result was shown to be true, whatever may be the law according to which the density of the strata varies.

It further results from these theoretical researches that the mean density of the entire terrestrial spheroid is about twice the mean density of its superficial crust.

It follows from this that the density of its central parts must greatly exceed twice the density of its crust.

It remains, therefore, to see how far these results of theory are in accordance with those of actual observation and measurement.

73. **Ellipticity of terrestrial spheroid by observation and measurement.** — If a terrestrial meridian were an exact circle, as it would necessarily be if the earth were an exact globe, every part of it would have the same curvature. But if it were an ellipse, of which the polar diameter is the lesser axis, it would have a varying curvature, the convexity being greatest at the equator, and least at the poles. If, then, it can be ascertained by observation, that the curvature of a meridian is not uniform, but that on the contrary it increases in going towards the Line, and diminishes in going towards the poles, we shall obtain a proof that its form is that of an oblate spheroid.

To comprehend the method of ascertaining this, it must be considered that the curvature of circles diminishes as their diameters are augmented. It is evident that a circle of one foot in diameter has a less degree of curvature, and is less convex than a circle one inch in diameter. But an arc of a circle of a given angular magnitude, such for example as 1°, has a length proportional to the diameter. Thus, an arc of 1° of a circle a foot in diameter, is twelve times the length of an arc of 1° of a circle an inch in diameter. The curvature, therefore, increases as the length of an arc of 1° diminishes.

If, therefore, a degree of the meridian be observed, and measured, by the process already explained (58), at different latitudes, and it is found that its length is not uniformly the same as it would be if the meridian were a circle, but that it is less in approaching the equator, and greater in approaching the pole, it will follow that the convexity or curvature increases towards the equator, and diminishes towards the poles; and that consequently the meridian has the form, not of a circle, but of an ellipse, the lesser axis of which is the polar diameter.

Such observations have accordingly been made, and the lengths of a degree in various latitudes, from the Line to 66° N. and to 35° S., have been measured, and found to vary from 363,000 feet on the Line to 367,000 feet at lat. 66°.

From a comparison of such measurements, it has been ascertained that the equatorial diameter of the spheroid exceeds the polar by $\frac{1}{300}$ of its length. Thus (72)

$$e = \frac{1}{300}.$$

74. **Variation of gravity by observation.**—The manner in which the variation of the intensity of superficial gravity at different latitudes is ascertained by means of the pendulum, has been explained in M. 505. From a comparison of these observations it has been inferred that the effective weight of a body at the pole exceeds its weight at the equator by about the $\frac{1}{187}$th * part of the whole weight.

75. **Accordance of these results with theory.**—By comparing these results with those obtained by Newton, on the supposition of the uniform density of the earth, a discrepancy will be found sufficient to prove the falsehood of that supposition. The value of e found by Newton is $\frac{1}{230}$, its actual value being $\frac{1}{300}$, and that of w $\frac{1}{230}$, its actual value being $\frac{1}{187}$.

On the other hand, the accordance of these results of observation and measurement with the more rigorous conclusions of later researches is complete and striking; for instance, if in the relation between e and w, explained in (72), we substitute for w the value $\frac{1}{187}$, determined by observation, we find the result as the value for e, which is obtained by computation founded on measurement, to be also, $\frac{1}{300}$.

76. **Actual linear dimensions of the terrestrial spheroid.**—It is not enough to know the proportions of the earth. It is required to determine the actual dimensions of the spheroid. The following are the lengths of the polar and equatorial diameters, according to the computations of the most eminent and recent authorities:—

	Bessel.	Airy.
	Miles.	Miles.
Polar diameter	7899·114	7899·170
Equatorial diameter	7925·604	7925·648
Absolute difference	26·490	26·478
Excess of the equatorial expressed in a fraction of its entire length	$\frac{1}{299·192}$	$\frac{1}{299·330}$

The close coincidence of these results supplies a striking example of the precision to which such calculations have been brought.

The departure of the terrestrial spheroid from the form of an exact globe is so inconsiderable that, if an exact model of it turned in ivory were placed before us, we could not, either by sight or touch, distinguish it from a perfect billiard ball. A figure of a meridian accurately drawn on paper could only be distinguished

* Different values are assigned to this — Sir John Herschel prefers $\frac{1}{194}$, the Astronomer Royal $\frac{1}{180}$. We have taken a mean between these estimates.

from a circle by the most precise measurement. If the major axis of such an ellipse were equal in length to the page now under the eye of the reader, the lesser axis would fall short of the same length less than the fortieth of an inch.

77. **Dimensions of the spheroidal equatorial excess.** — If a sphere N *q* S *q* be imagined to be inscribed within the terrestrial spheroid having the polar axis N S, *fig.* 22., for its diameter, a spheroidal shell will be included between its surface and that of the spheroid composed of the protuberant matter, having a thickness Q *q* of 26 miles at the equator, and becoming gradually thinner in proceeding to the poles, where its thickness vanishes. This shell, which constitutes the equatorial excess of the spheroid, and which has a density not more than half the mean density of the earth, the bulk of which, moreover, would be imperceptible upon a mere inspection of the spheroid, is nevertheless attended with most important effects, and by its gravitation is the origin of most striking phenomena not only in relation to the moon, but also to the far more distant mass of the sun.

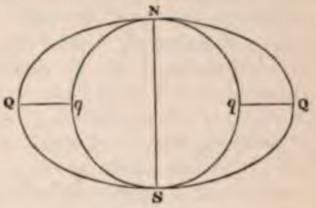


Fig. 22.

78. **Density and mass of the earth by observation.** — The magnitude of the earth being known with great precision, the determination of its mass and that of its mean density become one and the same problem, since the comparison of its mass with its magnitude will give its mean density, and the comparison of its mean density with its magnitude will give its mass.

The methods of ascertaining the mass or actual quantity of matter contained in the earth are all based upon a comparison of the gravitating force or attraction which the earth exerts upon an object with the attraction which some other body, whose mass is exactly known, exerts on the same object. It is assumed, as a postulate or axiom in physics, that two masses of matter which at equal distances exert equal attractions on the same body must be equal. But as it is not always possible to bring the attracting and attracted bodies to equal distances, their attractions at unequal distances may be observed, and the attractions which they would exert at equal distances may be thence inferred by the general law of gravitation, by which the attraction exerted by the same body increases as the square of the distance from it is diminished.

79. **Dr. Maskelyne's solution by the attraction of Schehallien.** — This celebrated problem consisted in determining the ratio

of the mean density of a mountain called Schehallien, in Perthshire, to that of the earth, by ascertaining the amount of the deviation of a plumb-line from the direction of the true vertical produced by the local attraction of the mountain.

To render this method practicable, it is necessary that the moun-

Fig. 23.

tain selected be a solitary one, standing on an extensive plain, since otherwise the deviation of the plumb-line would be affected by neighbouring eminences to an extent which it might not be possible to estimate with the necessary precision. It was considered by Dr. Maskelyne that no eminence sufficiently considerable exists near enough to Schehallien to produce such disturbance.

The accuracy of this inference is however rather doubtful. Mr. Airy, who has personally examined the mountain, says: "The mountain is nearly surrounded by other mountains, of which one is much higher than itself; the geology also of the country is complicated." The exact disturbance due to the attraction of the mountain would for these reasons be extremely difficult to discover.

The mountain ranging east and west, two stations were selected on its northern and southern acclivities, so as to be in the same meridian, or very nearly so. A plumb-line, attached to an instrument called a zenith sector, adapted to measure with extreme accuracy small zenith distances, was brought to each of these stations, and the distance of the same star, seen upon the meridian from the directions of the plumb-line, were observed at both places.

The difference between those distances gave the angle under the two directions of the plumb-line. This will be more clearly understood by reference to *fig.* 23, where P and P′ represent the points of suspension of the two plumb-lines. If the mountain were removed, they would hang in the directions P C and P′ C of the earth's centre, and their directions would be inclined at the angle P C P′. But the attraction exerted by the interjacent mass produces on each side a slight deflection towards the mountain, so that the two directions of the plumb-line, instead of converging to the centre of the earth C, converge to a point *c* nearer to the surface, and form with each other an angle P *c* P′ greater than P C P′ by the sum of the two deflections C P *c* and C P′ *c*.

Now by means of the zenith sector the distances S Z and S Z′ of the points Z and Z′ from any star such as S, can be observed with a precision so extreme as not to be subject to a greater error than a small fraction of a second. The difference of these distances will be—

$$SZ' - SZ = ZZ',$$

the apparent distance between the two points Z and Z′ on the heavens to which the plumb-line points at the two stations. This distance expressed in seconds gives the magnitude of the angle P *c* P′ formed by the directions of the plumb-line at the two stations, which is the sum of the deflection produced by the local attraction of the mountain.

If the mountain were not present, the angle P C P′ could be ascertained by the zenith sector; but as the indications of that instrument have reference to the direction of the plumb-line, it is rendered inapplicable in consequence of the disturbing effect of the mountain.

To determine the magnitude of the angle P C P′, therefore, the direct distance between the stations P and P′ is ascertained by making a survey of the mountain which, as will presently appear, is also necessary, in order to determine its exact volume. For every hundred feet in the distance between P and P′ there will be 1″ in the angle P C P′ (60). Finding, therefore, the direct distance between P and P′ in feet, and dividing it by 100, we shall have the angle P C P′ in seconds.

In the case of the experiment of Dr. Maskelyne, which was made in 1774, the angle PCP′ was found to be 41″, and the angle PcP′ 53″. The sum of the two deflections was therefore 12″.

The survey of the mountain supplied the data necessary to determine its actual volume in cubic miles, or fraction of a cubic mile. An elaborate examination of its stratification, by means of sections,

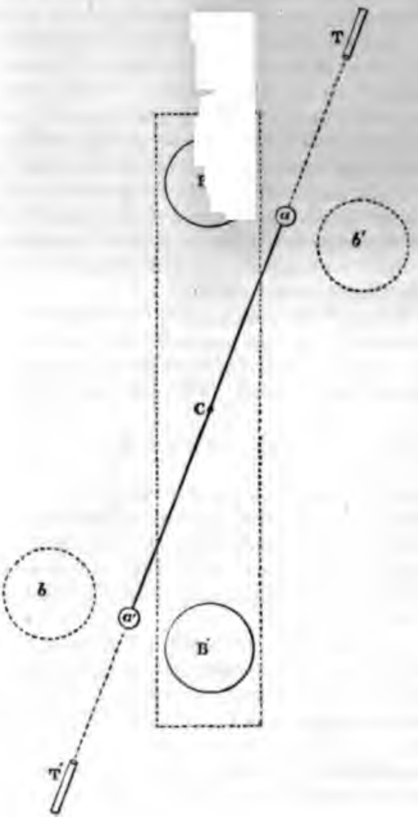


Fig. 24.

borings, and the other usual methods, supplied the data necessary to determine the weights of its component parts, and thence the weight of its entire volume: and the comparison of this weight with its volume gave its mean density.

The mean density of the earth resulting from this experiment is about five times that of water.

80. **Cavendish's solution.** — At a later period Cavendish made the experiment which bears his name, in which the attraction exerted by the earth upon a body on its surface was compared with the attraction exerted by a large metallic ball on the same body; and this experiment was repeated still more recently by Dr. Reich, and by the late Mr. Francis Baily, as the active member of a committee of the Royal Astronomical Society of London. All these several experimenters proceeded by methods which differed only in some of their practical details, and in the conditions and precautions adopted to obtain more accurate results.

In the apparatus used by Mr. Baily, the latest of them, the attracting bodies with which the globe of the earth was compared were two balls of lead, each a foot in diameter. The bodies upon which their attraction was manifested were small balls, about two inches in diameter. The former were supported on the ends of an oblong horizontal stage, capable of being turned round a vertical axis supporting the stage at a point midway between them. Let *fig.* 24 represent a plan of the apparatus. The large metallic balls B and B′ are supported upon a rectangular stage represented by the dotted lines, and so mounted as to be capable of being turned round its centre C in its own plane. Two small balls *a a′*, about two inches in diameter, are attached to the ends of a rod, so that the distance between their centres shall be nearly equal to B B′. This rod is supported at C by two fine wires at a very small distance asunder, so that the balls will be in repose when the rod *a a′* is directed in the plane of the wires, and can only be turned from that plane by the action of a small and definite force, the intensity of which can always be ascertained by the angle of deflection of the rod *a a′*. The exact direction of the rod *a a′* is observed, without approaching the apparatus, by means of two small telescopes T and T′, and the extent of its departure from its position of equilibrium may be measured with great precision by micrometers.

In the performance of the experiment a multitude of precautions were taken to remove or obviate various causes of disturbance, such as currents of air, which might arise from unequal changes of temperature which need not be described here.

The large balls being first placed at a distance from the small ones, the direction of the rod in its position of equilibrium was observed with the telescopes T T′. The stage supporting the large balls was then turned until they were brought near the small ones, as represented at B B′. It was then observed that the small balls were attracted by the large ones, and the amount of the deflection of the rod *a a′* was observed.

The frame supporting the large balls was then turned until B was brought to *b*, and B′ to *b*′, so as to attract the small balls on the other side, and the deflection of *a a*′ was again observed. In each case the amount of the deflection being exactly ascertained, the intensity of the deflecting force, and its ratio to the weight of the balls, became known.

The properties of the pendulum supplied a very simple and exact means of comparing the attraction of the balls B and B′ with the attraction of the earth. The balls *a a*′ were made to vibrate through a small arc on each side of the position which the attraction gave them, and the rate of their vibration was observed and compared with the rate of vibration of a common pendulum. The relative intensity of the two attractions was computed from a comparison of these rates by the principles established in (M. 505). The precision of which this process of observation is susceptible may be inferred from the fact that the whole attraction of the balls B B′ upon *a a*′ did not amount to the 20-millionth part of the weight of the balls *a a*′, and that the possible error of the result did not exceed 2 per cent. of its whole amount.

The attraction which the balls B B′ would exert on *a a*′, on the supposition that the mean density of the earth is equal to that of the metallic balls B B′, was then computed and found to be less than the actual attraction observed, and it was inferred that the density of the earth was less than that of the balls B B′ in the same ratio.

The result of this experiment as determined by Mr. Baily gave the mean density of the earth 5·67 times greater than that of water.

The apparatus for determining by immediate observation the mean density of the earth, will be more easily understood by reference to *figs.* 25, 26, and 27, assisted by the following explanation.

In *fig.* 25, the two great balls W W are presented obliquely and foreshortened, their true position being represented in the ground plan *fig.* 26. The small balls *a a*′ *fig.* 24 correspond with *x x fig.* 25, and the rod connecting them with *h h*. The two small leaden balls *x x* are suspended to the extremities of the horizontal rod *h h*, supported at its middle point by a vertical metallic wire *l g m*. The two wires *g h* are arranged, connecting the extremities of *h h* with the point *g*, to prevent the flexure of the rod *h h* by the weight of the balls *x x*. The suspending wire *l g m*, the oblique wires *g h*, the rod *h h*, and the balls *x x* are enclosed in a lightly constructed case, A B C D E F, to prevent the least effect of the agitation of the surrounding air. This box is sustained by four vertical supports, two of which are represented in S. The two great balls W W are suspended by two vertical rods connected above by the piece *r* P *r*, which is terminated at P by the

rod P p, which traverses a fixed beam. A pulley M M is fixed upon the rod P p, by which the whole apparatus supporting the balls W W can be turned round the vertical axis.

Let us now suppose the balls W W to be placed in the vertical plane at right angles to the rod h h. In that position, their attractions upon the balls x x, being equal and contrary, will equilibrate,

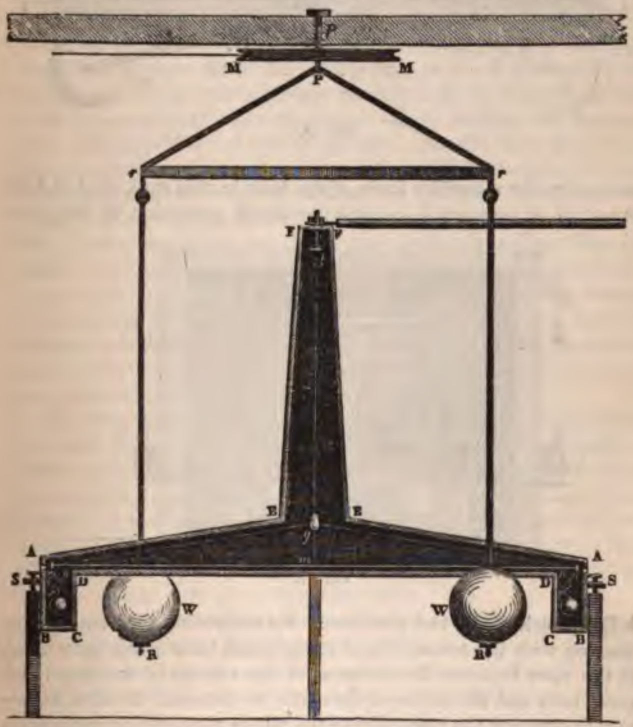


Fig. 25.

and the balls x x will remain undisturbed. If we bring the two large balls W W into the position represented in *fig.* 26., they will attract the small balls x x, and will make the lever h h turn upon its vertical axis, in consequence of which, a slight degree of torsion will be given to the wire l g, which torsion will balance the effect of the attraction of the balls W W. If the balls W W are turned to the position w w indicated by the dotted lines, the small balls x x will be again attracted, but in contrary directions, and with equal forces.

It is evident that the total angle of torsion through which the wire *g l* will be turned by the rod *h h* in the two cases, will repre-

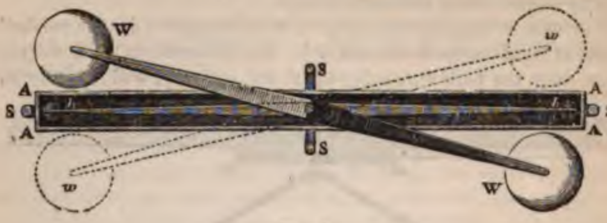


Fig. 26.

sent twice the attractive force of the balls in this case, so that half the angle of torsion will express the actual attraction of the great

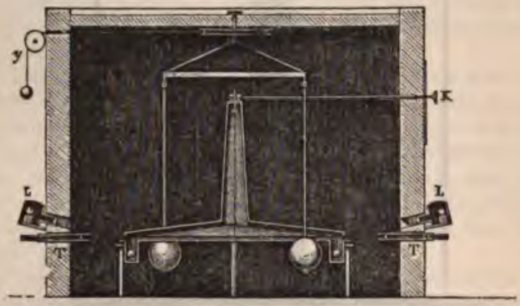


Fig. 27.

balls in each of the two positions. By comparing the force of attraction with the actual weight of the small balls *x*, taking account of the ratio between the distances of the centres of the small and great balls and the radius of the earth, we have all the data necessary to compare the attraction of the whole mass of the earth upon the small balls, with the attraction of the mass W upon them.

The actual value of force exerted by the torsion of the wire *l g* is determined by turning the balls *x x* from their position of equilibrium, and allowing them to vibrate to the right and left alternately of the position of equilibrium. The time of vibration will in that case determine the force of torsion, upon the same principle as the time of vibration of a common pendulum determines the force of gravity.

The manner in which Cavendish disposed his apparatus in an in-

closed chamber, so as to remove it from all disturbing causes arising from the agitation of the surrounding air, is represented in *fig.* 27. The deviation of the lever *h h*, whether produced by the attraction of the great balls or by the oscillation of the small ones, on either side of the position of equilibrium, was observed by the two telescopes T T directed towards the extremities of the lever *h h*. Two small divided rules *n n* were adapted to the extremities of the lever *h h*, and moved with it behind two small openings through which they were visible by the telescopes T T. The lamps L L projected light by reflectors upon these two small rules *n n*. A horizontal rod, terminated by a button K, communicated by its inner extremity with the support of the vertical wire *l g*, by making the button K turn this support round its vertical axis. In this way, the rod *h h* would always be adjusted to the position which it ought to have, when the vertical wire *l g* suffered no torsion. Finally, a cord passed through the groove of a pulley M M, *fig.* 25. fixed horizontally above the piece P *r*. The two cords proceeding from this issued from the chamber by two lateral openings, passed each other in the groove of a vertical pulley *y*, and supported weights destined to give them the necessary tension. It was sufficient to draw one of these two cords to turn the pulley M M, drawing with it the two large balls W W, so as to place these two balls in any desired position with relation to the apparatus.

81. **The Harton pendulum experiments.**—The last determination of the mean density of the earth which it is necessary to mention, is that resulting from the experiments undertaken by the Astronomer Royal, Mr. Airy, at the Harton Colliery, near South Shields, in the month of October, 1854. It would be out of place here, however, to give a lengthened detail of the various methods adopted in carrying out this important experiment, a general and concise outline only must therefore suffice.

The observations at the mine consisted of accurately noting simultaneously at two stations, the vibrations of an invariable pendulum in comparison with the vibrations of a clock pendulum placed immediately behind, one station being on the surface in a building prepared for the occasion, and the other almost vertically below, at a depth of about 1260 feet, the object being to ascertain the difference of the force of gravity acting on the two detached pendulums.

For this purpose, the detached pendulum was suspended on a firm iron stand, by means of a projecting piece of hard steel, one edge of which is ground to a knife-edge, resting on planes of polished agate. Friction is thus nearly, if not altogether, avoided. Behind the pendulum the clock was placed. A small inclined disk covered with gold leaf, and illuminated by a lamp, was fixed to the bob of the clock pendulum. This disk was viewed at a short

distance by means of a telescope. Immediately in front of the disk a long narrow tail projecting from the bob of the detached pendulum was suspended, the disk being invisible when both pendulums were in a vertical position. If the clock pendulum were made to vibrate while the detached pendulum was at rest, its disk would be seen on both sides of the pendulum tail. A pair of cheeks was attached to the clock-case between the two pendulums, having an opening between them which admitted of adjustment. When the detached pendulum was still at rest, the cheeks were moved towards the centre till the vibrating disk could not be seen past the edges of the pendulum tail; when this was done satisfactorily the apparatus was ready for use. Supposing the two pendulums are both vibrating; if they do not pass the vertical positions at the same time, the pendulum tail does not cover the opening between the adjustable cheeks at the instant when the disk is passing, which is therefore visible to the observer. When they pass together the disk cannot be seen, the two pendulums being in coincidence. The exact times of successive coincidences were observed, from which could easily be inferred the rate of one pendulum over the other. These observations were made simultaneously at the upper and lower stations on precisely the same system. Having thus obtained the rate of each detached pendulum in comparison with its own clock, it was necessary that the comparative rates of the two clocks should be determined with the greatest accuracy. This was effected by means of galvanic signals, a communication being made between the two stations by wires passing down the shaft. A galvanic needle was placed near each clock-face, so that each signal was observed at the same instant by the two observers. From these comparisons the rate of one clock over the other was easily found, and also the comparative rate of the two detached pendulums.

The observations were completed in three weeks, the detached pendulums being reversed in the second week; in the third, the pendulums were interchanged at the commencement, and in the middle of the week, forming four complete series of observations. To eliminate any liability of error which might arise if no interchange took place, the detached pendulums were, therefore, alternately mounted at the upper and lower stations. Six observers from different observatories, under the superintendance of Mr. Dunkin, of the Royal Observatory, gave their personal assistance.

A careful survey of the neighbouring country was made, as well as of the different strata which composed the shell between the two stations. One hundred and forty-two different specimens were found, and the specific gravity of the principal determined.

The result of the experiment gave 6·57 for the value of the mean

density of the earth above that of water. This result is much larger than those obtained from former researches, but the Astronomer Royal considers it entitled to compete with the others on, at least, equal terms.

CHAPTER V.

APPARENT FORM AND MOTION OF THE FIRMAMENT.

82. **Aspect of the firmament.** — If we examine the heavens with attention on clear starlight nights, we shall soon be struck with the fact, that the brilliant objects scattered over them in such incalculable numbers maintain constantly the same relative position and arrangement. Every eye is familiar with certain groups of stars called constellations. These are never observed to change their relative position. A diagram representing them now would equally represent them at any future time; and if a general map be made, showing the relative arrangement of these bodies on any night, the same map will represent them with equal exactness and fidelity on any other night. There are a few, among many thousands, which are exceptions to this, with which, however, for the present we need not concern ourselves.

83. **The celestial hemisphere.** — The impression produced upon the sight by these objects is that they are at a vast distance, but all at the same distance. They seem as though they were attached in fixed and unalterable positions upon the surface of a vast hemisphere, of which the place of the observer is the centre. Setting aside the accidental inequalities of the ground, the observer seems to stand in the centre of a vast circular plane, which is the base of this celestial hemisphere.

84. **Horizon and zenith.** — This plane, extended indefinitely around the observer, meets the celestial hemisphere in a circle which is called the HORIZON, from the Greek word ὁρίζειν (orizein), to *terminate* or *bound*, being the boundary or limit of the visible heavens.

The centre point of the visible hemisphere — that point which is perpendicularly above the observer, and to which a plumb-line suspended at rest would be directed — is called the ZENITH.

85. **Apparent rotation of the firmament.** — A few hours' attentive contemplation of the firmament at night will enable any common observer to perceive, that although the stars are, relatively to each other, fixed, the hemisphere, *as a whole*, is in motion. Looking at the zenith, constellation after constellation will appear

to pass across it, having risen in an oblique direction from the horizon at one side, and, after passing the zenith, descending on the other side to the horizon, in a direction similarly oblique. Still more careful and longer continued observation, and a comparison, so far as can be made by the eye, of the different directions successively assumed by the same object, creates a suspicion, which every additional observation strengthens, that the celestial vault has a motion of slow and uniform rotation round a certain diameter as an axis, carrying with it all the objects visible upon it, without in the least deranging their relative positions or disturbing their arrangement.

Such an impression, if well founded, would involve, as a necessary consequence, that a certain point in the heavens placed at the extremity of the axis of its rotation, would be fixed, and that all other points would appear to be carried around it in circles; each such point preserving therefore, constantly, the same distance from the point thus fixed.

86. **The pole star.** — To verify this inference, we must look for a star which is not affected by the apparent rotation of the heavens, which affects more or less every other star.

Such a star is accordingly found, which is always seen in the same direction, — so far at least as the eye, unaided by more accurate means of observation, can determine.

The place of this star is called the POLE, and the star is called the POLE STAR.

87. **Rotation proved by instrumental observation.** — Mere visual observation, however, can at most only supply grounds for probable conjecture, either as to the rotation of the sphere, or the position of its pole, if such rotation take place. To verify this conjecture, to determine with certainty whether the motion of the sphere be one of rotation, and if so, to ascertain with precision the direction of the axis round which this rotation takes place, its velocity, and, in fine, whether it be uniform or variable, — are problems of the highest importance, but which are altogether beyond the powers of mere visual observation unaided by instruments of precision.

88. **Exact direction of the axis and position of the pole.** — Suppose a telescope of low magnifying power, supplied with micrometric wires (11), to be directed to the pole star, so that the star may be seen exactly upon the intersection of the horizontal and vertical wires. If this star were precisely at the extremity of the axis of the hemisphere, or at the pole, it would remain permanently in this position notwithstanding the rotation of the firmament. Such is not, however, found to be the case. The star will appear

to move; but if the magnifying power of the telescope be low enough it will not leave the field of view. It will appear to move in a small circle, the diameter of which is about 3°. The telescope may be so adjusted that the star will move in a circle round the intersection of the wires as a centre, which would be the true position of the POLE, round which the pole star is carried in a circle, at the distance of about 1½°, by the rotation of the sphere.

89. **Rotation of firmament proved by equatorial.**—Now, to establish, by means of the equatorial, the fact that the firmament really has a motion of apparent rotation with a velocity rigorously uniform round the axis, let the telescope be first directed to any star, *o*, *fig.* 13, for example, so that it shall be seen bisected by the middle wire. The line of collimation will then be directed to the star, and the angle OCN′ or the arc ON′ will express the apparent distance of such a star from the pole *p*.

Let the instrument be then turned upon its axis from east to west (that is, in the same direction as the rotation of the firmament), through any proposed angle, say 90°, and let it be fixed in that position. The firmament will follow it, and after a certain interval the same star will be seen again bisected by the middle wire; and in the same manner, whatever be the change of position of the instrument upon its axis, provided the direction of the telescope upon the arc O N′, *fig.* 13, be not changed, the star will always arrive, after an interval more or less, according to the angle through which this instrument has been turned, upon the middle wire.

It follows, therefore, from this, that the particular star here observed is carried in a circle round the heavens, always at the same distance, *o p*, from the celestial pole.

The same observations being made with a like result upon every star to which the telescope is directed, it follows that the motion of the firmament is such that all objects upon it describe circles at right angles to its axis, each object always remaining at the same distance from the pole.

This is precisely the effect which would be produced by the rotation of the heavens round an axis directed to the pole from the place of the observer.

But it remains to ascertain the time of rotation, and whether the rotation be uniform.

If the telescope be directed as before to any star, so that it shall be seen on the middle wire, let the instrument be then fixed, being detached from the clock-work, and let the exact time be noted. On the following night, at the approach of the same hour, the same star will be seen approaching to the same position, and it will at length arrive again upon the wire. The time being again exactly observed, it will be found that the interval of solar time which

has elapsed between the two successive passages of the star over the wire is

$$23^h\ 56^m\ 4^s{\cdot}09.$$

Such is, therefore, the solar time in which the celestial sphere makes one complete revolution, and this time will be always found to be the same, whatever be the star to which the telescope is directed.

To prove that not only every complete revolution is performed in the same time, but that the rotation during the same revolution is uniform, let the instrument, after being directed to any star, be turned in the direction of the motion of the sphere through any proposed angle, 90° for example. It will be found that the interval which will elapse between the passage of the star over the wires in the two positions will, in this case, be the fourth part of $23^h\ 56^m\ 4^s{\cdot}09$; and, in general, whatever be the angle through which the instrument may be turned, the interval between the passages of the same star over the wires in the two positions will bear the same proportion to $23^h\ 56^m\ 4^s{\cdot}09$, as the angle bears to 360°.

It follows, therefore, that the apparent rotation of the heavens is rigorously uniform.

It will be observed that the time of one complete revolution is $3^m\ 55^s{\cdot}91$ less than twenty-four hours, or a common day. The cause of this difference will be explained hereafter.

90. **Sidereal time.**—The time of one complete revolution of the firmament is called a SIDEREAL DAY. This interval is divided, like a common day, into 24 hours, each hour into 60 minutes, and each minute into 60 seconds.

Since in 24 sidereal hours the sphere turns through 360°, and since its motion is rigorously uniform, it turns through 15° in a sidereal hour, and through 1° in four sidereal minutes.

91. **The same apparent motion observed by day.**—It may be objected that although this description of the movement of the heavens accords with the appearances during the night, there is no evidence of the continuance of the same rotation during the day, since in a cloudless firmament no object is visible except the sun, which being alone cannot manifest the same community of motion as is exhibited by the multitudinous objects which, being crowded so thickly on the firmament at night, move together without any change in their apparent relative position. To this objection it may be answered that the moon is occasionally seen in the day-time as well as the sun; and, moreover, that before sunset and after sunrise the planets Jupiter and Venus are occasionally seen under favourable atmospheric circumstances. Besides, with telescopes of sufficient power properly directed, all the brighter stars can be dis-

tinctly seen when not situated very near the position of the sun. Now, in all these cases, the objects thus seen appear to be carried round by the same motion of the firmament, which is so much more conspicuously manifested in the absence of the sun and at night.

92. **Certain fixed points and circles necessary to express the position of objects on the heavens.**—It will greatly contribute to the facility and clearness with which the celestial phenomena and their causes shall be understood if the student will impress upon his memory the names and positions of certain fixed points, lines, and circles of the celestial sphere, by reference to which the position of objects upon it are expressed. Without incumbering him with a more complex nomenclature than is indispensably necessary for this purpose, we shall therefore explain some of the principal of these landmarks of the heavens.

93. **Vertical circles, zenith, and nadir.**—If from the place of the observer a straight line be imagined to be drawn perpendicular to the plane of the horizon, and to be continued indefinitely both upwards and downwards, it will meet the visible hemisphere at its vertex, the ZENITH, and the invisible hemisphere, which is under the plane of the horizon, at a corresponding point called the NADIR.

If a plane be supposed to pass through the place of the observer and the zenith, it will meet the celestial surface in a series of points, forming a circle at right angles to the horizon. Such a circle is called a VERTICAL CIRCLE, or, shortly, a VERTICAL.

If this plane be supposed to be turned round the line passing upwards to the zenith, it will assume successively every direction round the observer, and will meet the heavens in every possible vertical circle.

The vertical circles, therefore, all intersecting at the zenith as a common point, divide the horizon as the divisions of the hours and minutes divide the dial-plate of a clock.

94. **The celestial meridian and prime vertical.**—That vertical which passes through the celestial pole is called the MERIDIAN.

The meridian is, therefore, the only circle of the heavens which passes at once through the two principal fixed points, the pole and the zenith.

It divides the visible hemisphere into two regions on the right and left of the observer; as he looks to the north, that which is on his right being called the EASTERN, and that which is on his left the WESTERN.

Another vertical at right angles to the meridian is called the PRIME VERTICAL. This is comparatively little used for reference.

95. **Cardinal points.**—The meridian and prime vertical divide the horizon at four points, equally distant, and therefore separated

by arcs of 90°. These points are called the CARDINAL POINTS. Those formed by the intersection of the meridian with the horizon are called the NORTH and SOUTH points, that which is nearest to the visible pole in the northern hemisphere being the north. Those formed by the intersection of the prime vertical with the horizon are called the EAST and WEST, that to the right of an observer looking towards the north being the east.

The cardinal points correspond with those marked on the card of a mariner's compass, allowance being made for the variation of the needle.

96. **The azimuth.**—The direction of an object, whether terrestrial or celestial, in reference to the cardinal points, or to the plane of the meridian, is called its AZIMUTH. Thus it is said to have so many degrees of azimuth east or west, according as the vertical circle, whose plane passes through it, forms that angle east or west of the plane of the meridian.

97. **Zenith distance and altitude.**—It is always possible to conceive a vertical circle, which shall pass through any proposed object on the heavens. The arc of such a circle between the zenith and the object is called its ZENITH DISTANCE.

The remainder of the quadrant of the vertical between the object and the horizon is called its ALTITUDE.

It is evident, therefore, that the altitude of the zenith is 90°, and the zenith distance of every point on the horizon is also 90°.

The arc of the meridian between the zenith and the pole is the zenith distance of the pole, and the arc of the meridian between the pole and the horizon is the altitude of the pole.

98. **Celestial equator.**—If a plane be imagined to pass through the place of the observer at right angles to the axis of the sphere, and to be continued to the heavens, it will meet the surface of the celestial vault in a circle which shall be 90° from the pole, and which will divide the sphere into two hemispheres, at the vertex of one of which is the visible or north pole, and at the vertex of the other the invisible or south pole.

This circle is called the CELESTIAL EQUATOR.

The several fixed points and circles described above will be more clearly conceived by the aid of the diagram, *fig.* 28, where O is the place of the observer, Z the zenith, P the pole, S Z P N the visible, and S p z N the invisible half of the meridian; S E N W is the horizon seen by projection as an oval, being, however, really a circle; N and S are the north and south, and E and W the east and west cardinal points. The points of the several circles which are below the horizon; are distinguished by dotted lines. The celestial equator is represented at Æ Q, and the prime vertical at Z W E z, both being looked at edgewise.

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A plane N *n*, drawn through the north cardinal point, cuts off a portion of the sphere, having the visible pole N at its centre, all of

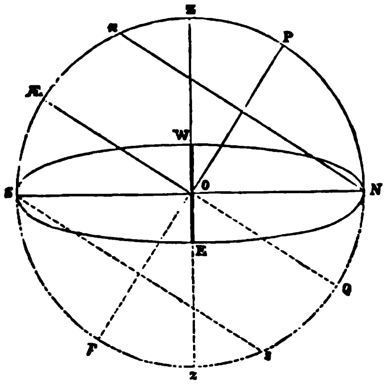

Fig. 28.

which is above the horizon; and a corresponding plane, S *s*, through the south cardinal point, cuts off a part, leaving the invisible pole at its centre, all of which is below the horizon.

99. **Apparent motion of the celestial sphere.**—Now, if the entire sphere be imagined to revolve on the line P O *p* through the poles as a fixed axis, making one complete revolution, and in such a direction that it will pass over an observer at O, looking towards N from his right to his left, carrying with it all the objects on the firmament, without disturbing their relative position and arrangement, we shall form an exact notion of the apparent motion of the heavens. All objects rise upon the eastern half, S E N, of the horizon, and set upon the western half, S W N. The objects which are nearer to the visible pole P than the circle *n* N never set; and those which are nearer to the invisible pole P than the circle S *s* never rise. Those which are between the equator Æ Q and the circle *n* N are longer above the horizon than below it; and those which are between the equator Æ Q and the circle S *s* are longer below the equator than above it. Objects, in fine, which are upon the equator are equal times below and above the horizon.

When an object rises, it gradually increases its altitude until it reaches the meridian. It then begins to descend, and continues to descend until it sets.

CHAPTER VI.

DIURNAL ROTATION OF THE EARTH.

100. **Apparent diurnal rotation of the heavens — its possible causes.** — The apparent diurnal rotation of the celestial sphere being such as has been explained, it remains to determine what is the real motion which produces it. Now it is demonstrable that it may be caused indifferently, either by a real motion of the sphere round the observer corresponding in direction and velocity with the apparent motion, or by a real motion of the earth in the contrary direction, but with the same angular velocity upon that diameter of the globe which coincides with the direction of the axis of the celestial sphere, and that no other conceivable motion would produce that apparent rotation of the heavens which we witness. Between these two we are to decide which really exists.

101. **Supposition of the real motion of the universe inadmissible.** — The fixity and absolute repose of the globe of the earth being assumed by the ancients as a physical maxim which did not even admit of being questioned, they perceived the inevitable character of the alternative which the apparent diurnal rotation of the heavens imposed upon them, and accordingly embraced the hypothesis, which now appears so monstrous, and which is implied in the term UNIVERSE*, which they have bequeathed to us.

It is true that owing to the imperfect knowledge which prevailed as to the real magnitudes and distances of the bodies to which this common motion was so unhesitatingly ascribed, the improbability of the supposition would not have seemed so gross as it does to the more enlightened inquirers of our age. Nevertheless, in any view of it, and even with the most imperfect knowledge, the hypothesis which required the admission that the myriads of bodies which appear upon the firmament should have, besides the proper motions of several of them, such as the moon and planets, of which the ancients were not unaware, motions of revolution with velocities so prodigious and so marvellously related that all should, in the short interval of twenty-four hours, whirl round the axis of the earth with the unerring harmony and regularity necessary to explain the apparent diurnal rotation of the firmament, ought to have raised serious difficulties and doubts.

* UNUS, *one*, and VERSUM, *turning*, or rotation,—turning with one common motion of rotation.

But with the knowledge which has been obtained by the labours of modern astronomers respecting the enormous magnitudes of the principal bodies of the physical universe, magnitudes compared with which, that of the globe of the earth dwindles to a mere point, and their immense distances, under the expression of which the very power of number itself almost fails, recourse to colossal units being necessary in order to enable it to express even the smallest of them, the hypothesis of the immobility of the earth, and the diurnal rotation of the countless orbs of magnitudes, so unconceivably filling the immensity of space, once every twenty-four hours round this grain of matter composing our globe, becomes so preposterous that it is rejected, not as an improbability, but as an absurdity too gross to be even for a moment seriously entertained or discussed.

102. **Simplicity and intrinsic probability of the rotation of the earth.**—But if any ground for hesitation in the rejection of this hypothesis existed, all doubt would be removed by the simplicity and intrinsic probability of the only other physical cause which can produce the phenomena. The rotation of the globe of the earth upon an axis passing through its poles, with an uniform motion from west to east once in twenty-four hours, is a supposition against which not a single reason can be adduced based on improbability. Such a motion explains perfectly the apparent diurnal rotation of the celestial sphere. Being uniform and free from irregularities, checks, or jolts, it would not be perceivable by any local derangement of bodies on the surface of the earth, all of which would participate in it. Observers upon the surface of our globe would be no more conscious of it, than are the voyagers shut up in the cabin of a canal boat, or transported above the clouds in the car of a balloon.

103. **Direct proofs of the earth's rotation.**—Irresistible, nevertheless, as this logical alternative is, the universality and antiquity of the belief in the immobility of the earth, and the vast physical importance of the principle in question have prompted inquirers to search for direct proofs of the actual motion of the earth upon its axis. Two phenomena have accordingly been produced as immediate conclusive proof of this motion.

104. **Proof by the descent of a body from a great height.**—It has been shown (M. 180) that a body descending from a great height does not fall in the true vertical line, which it would if the earth were at rest, but eastward of it, which it must, if the earth have a motion of rotation from west to east.

If a high tower or steeple be erected on the surface of the earth, it is evident that, in consequence of the revolution of the globe upon its axis, the top of the tower will be moved in a greater diurnal circle than the base C, being more distant from the common

centre round which the entire world is moved. The top of the tower, therefore, and anything placed upon it, has a greater velocity from west to east, which is the direction of the earth's rotation, than has the bottom.

Now if we imagine a heavy ball to be let fall from the top of the tower towards the base, this ball will be affected by two motions: 1st, that which it has in common with the top of the tower from west to east, in virtue of the earth's diurnal motion; and 2ndly, that vertical motion which it has in falling. The course it will follow will therefore depend on the combination of these two motions, and it will strike the ground at a point east of that which it occupied at the commencement of its fall, by a space equal to that through which the top of the tower is carried during the time of the fall. But during this same interval, the base of the tower is also moving eastward, but, as has been explained, through a less space.

Since the ball is carried eastward through the space through which the top of the tower is moved, while the base of the tower is carried eastward through a less space, the ball, instead of falling at the base of the tower, which it would do, if there were no diurnal rotation of the earth, will fall just so much east of the base as is equal to the difference between the motion of the top and the motion of the bottom of the tower.

This will be rendered more intelligible by *fig.* 29., in which A C may be supposed to represent the tower at the moment when the ball is disengaged from A, O being the centre of the earth, to which the vertical line A C is directed. Let us suppose that in the time of the fall, the earth in its revolution moves through the angle C O C′. In that case the position of the tower at the moment the ball comes to the surface of the earth will be A′ C′. The ball meanwhile, during its fall retaining the velocity eastward, which it had at the moment it was dismissed from A, will fall at a distance eastward of C equal to A A′. But since A A′ is greater than C C′, the distance at which the ball will strike the ground eastward of C will be necessarily greater

Fig. 29.

than C C′ by the difference between A A′ and C C′. If, then, we take C B = A A′, B will be the point at which the ball will strike the ground, the tower then being in the position A′ C′. The distance C′ B of the point B eastward of the foot of the tower, will then be the difference between the arc described by the top of the tower, and the arc described by the bottom of the tower in the time of the fall.

Since the distance B C′ must necessarily be extremely minute, it might be supposed that such an experiment, however beautiful in theory, would be impracticable, the quantity which would indicate the effect of the rotation being smaller than could be correctly measured. The experiment, nevertheless, was performed with some success when first proposed on the leaning tower of Bologna, and has since been repeated, under much more favourable circumstances, and with results much more exact, by M. Reich in the shaft of a mine near Freyberg. The depth of the shaft, and consequently the height of the fall, was in this case 520 feet, and a mean of several experiments showed that the eastern deviation amounted to 1·1 inch, while the calculation of the distance eastward, at which the ball ought to have fallen, allowing for the earth's actual rotation, was 1·086 inch. The difference between the result of the experiment and the calculation by theory was, therefore, less than the seventieth part of an inch.

105. **Foucault's experimental illustrations.**—The diurnal rotation of the earth could obviously be rendered apparent, provided any line or plane could be found upon the earth's surface which would not participate in the motion of rotation, since in that case the relative position of all objects referred to such line or plane, would be changed from hour to hour, as the earth turns upon its axis. It is upon this simple principle that the method of illustration contrived by M. Leon Foucault, has been based. As this experiment has been repeated in many places, has excited much attention, and has been the subject of much discussion, it may be worth while to develop the principles upon which it depends, somewhat fully.

It must be first observed that the rotation of a pendulous mass around the line of direction of the string by which it is suspended will not produce any change in the plane of vibration. This may be easily proved experimentally by imparting to the point of suspension of the pendulum a rotatory motion by which the wire or string suspending the pendulous mass can be made to revolve. The pendulum being put in vibration, it will be found that such motion of rotation will not in any way affect the plane of its oscillation.

If we suppose a pendulum to be suspended immediately over the

north pole of the earth and put in vibration, the plane of its oscillation will not be affected, therefore, by the rotation which its point of suspension will in that case have in common with the earth. The earth will, therefore, revolve under the pendulum while the plane of oscillation retains a fixed direction. The observer, meanwhile, being unconscious of the earth's rotation, the plane of oscillation of the pendulum will appear to him to have a motion of uniform rotation round the axis of suspension, one complete revolution being made in $23^h\ 56^m$. This apparent rotation of the plane of oscillation will moreover take place in the same direction as that in which the hand of a watch would move, or in which a right handed screw would be turned.

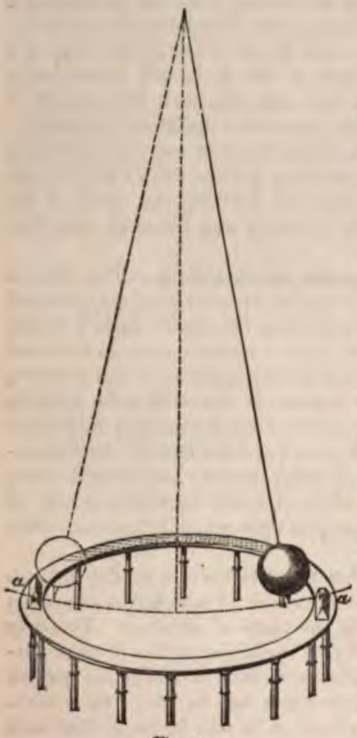

Fig. 30.

Such being the effect produced upon the observer, it is not quite correct to say that this experiment renders visible the rotation of the earth, since, in fact, it does not render that phenomenon more visible than does the apparent rotation of the firmament. In the one case, as in the other, an apparent motion is perceived, which is produced by the real rotation of the earth; and it is only by the result of reasoning upon the phenomena that the observer in the one case, as in the other, arrives at the conclusion that the apparent motion which he sees is an optical effect caused by the real rotation of the earth, of which he is totally unconscious.

The first experiments on this principle made by M. Foucault, took place in the Pantheon at Paris. An iron wire about 210 feet in length was attached by its upper extremity to a metal plate fixed in the centre of the cupola of the building. It supported at its lower extremity a large and ponderous

copper ball. When this pendulum was put in oscillation, it moved between its extreme limits very slowly, the time of oscillation being about 8 seconds. In order to render more sensible the rotation of the plane of oscillation round the axis of the pendulum, little mounds of sand, *a, a, fig.* 30, were placed upon a circle formed round the axis of oscillation, and a point projecting from the ponderous ball struck at each oscillation the ridge of this mound, throwing off a small portion of the sand; and thus by the continued motion of the plane of oscillation, the top of the ridge was gradually cut off, leaving a flat surface instead of an angular edge as indicated in the figure. On starting the pendulum it was of great importance that at the commencement it should receive no lateral motion, and that it should be merely abandoned to the action of gravity, without any other disturbing force. To ensure this, at the commencement of the operation, the pendulous ball was drawn to the extreme limit of its intended range, and tied there by a thread of silk, *b, fig.* 31, to a fixed point. It was started by burning the silk by means of a match or taper, at a point near the ball.

Fig. 31.

This experiment has been repeated not only by M. Foucault himself, but by many other observers in different parts of the world, and though it has not, as far as we are informed, been continued in any single case so long as to allow the plane of oscillation to make a complete revolution, its continuance has been sufficient to determine the angular velocity of the plane of oscillation.

M. Foucault has more recently contrived another form of experiment, by which the earth's rotation is demonstrated by exhibiting another apparent motion artificially produced by it. This second experiment is founded upon a principle of mechanics, in virtue of which a solid body, whose form is symmetrical with relation to a particular line, receiving a motion of rotation round that line, the direction of such axis of rotation will remain invariable whatever motion of translation may be imparted to the rotating body. If, therefore, it can be so contrived that a body shall be thus put in rapid rotation round its axis of symmetry, and placed in circumstances so as not to be disturbed by the force of gravity, this body, while it is carried round with the diurnal rotation of the earth, will preserve the direction of its axis of rotation unchanged. While the direction of this axis therefore is fixed, the position of all bodies round it being continually changed by the rotation of the earth, an observer, unconscious of the change, will refer the motion to the axis itself; consequently that axis will appear to have such

a motion as would result from the relation between the bodies moved by the earth's rotation, and its own fixed direction.

M. Foucault has realised this by an instrument to which he has given the name of *gyroscope*. A heavy metallic ring *a a*, *figs.* 32 and 33, is mounted upon an axis *b b*, which is fixed to its centre and perpendicular to its lateral faces. This disk, which is very massive, is so formed, that its matter shall be principally collected round its circumference, the central part being comparatively light. The axis *b b* is supported at its two extremities by two pivots round which the disk *a a* can turn freely. These two pivots are formed in a ring *c c* furnished with two knife-edges like those upon which the beam of a balance is suspended. These knife-edges *d d* rest in cavities formed for them at two opposite points of the vertical ring *e e*. This ring itself is suspended by a wire of some length which allows it to turn freely round the vertical line on which the wire is directed; and to prevent the wire with what it supports from receiving a pendulous motion from any disturbing cause, the ring is furnished below with a fine point, which enters a hole large enough to allow it to turn freely without friction. This mode of suspension of the disk *a a*, and the axis *b b*, which is united with it, evidently allows the direction of the axis *b b* to vary in all possible ways. By making the ring *e e* turn round the vertical, which passes through the suspending wire and through the inferior point, the axis *b b* can be directed in any vertical plane whatever. In like manner, by making the ring *c c* turn upon the knife-edges *d d*, the inclination of the axis *b b* can be varied at will, and these two motions can be produced without any sensible variation whatever.

Fig. 32.

This apparatus has been constructed with the most exquisite degree of perfection by M. G. Froment of Paris, so that the centre of gravity of the disk *a a* is precisely upon its axis of rotation, and the centre of gravity of the range *c c* is found also exactly upon the axis of the two knife-edges *d d*. It follows from this, *first*, that gravity has no effect whatever upon the motion of rotation of the disk round its axis of symmetry; and *secondly*, that it cannot in any manner tend to vary the inclination of the axis *b b*, by making the ring *c c* turn round the line of suspension formed by the knife-edges.

To perform the experiment, the part of the apparatus which is represented separately in *fig.* 32 is taken off, and is placed on a machine adapted to impart to the disk *a a* an extremely rapid motion of rotation by means of the small-toothed pinion *o*. When the

disk is thus put in rotation, it is again placed with the ring *cc* in the position indicated in *fig.* 33. The axis *bb* having thus the hori-

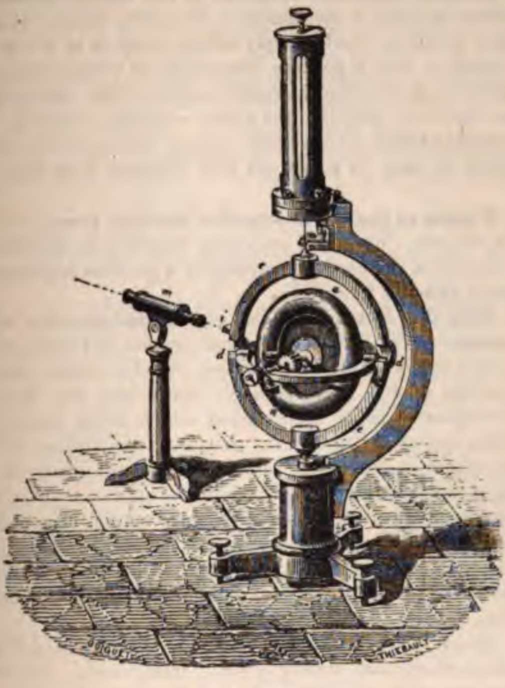

Fig. 33.

zontal direction, makes an angle with the axis of the earth, and will consequently appear to be moved round this line; but this apparent motion can only be produced in so far as the ring *c c* turns by degrees round the knife-edges *d d*, and at the same time the vertical ring *e e* turns round the sustaining wire. This last movement can be observed by the aid of a microscope *m* placed near the apparatus, and directed to a small divided plate *i* which the ring *e e* carries. The divisions of this little plate pass one by one before the micrometer wires of the microscope absolutely in the same manner as stars are observed to pass before the micrometer wires of an astronomical telescope.

The apparent motion is obviously due to the rotation of the earth

referred to the fixed direction of the axis of symmetry of the rotating ring.

106. **Analogy supplies evidence of the earth's rotation.**—The obvious analogy of the planets to the earth, which will appear more fully hereafter, would supply strong evidence in favour of the earth's rotation, even if positive demonstration were wanting. All the planets are globes like the earth receiving light and heat from the same luminary, and, like the earth, revolving round it. Now all the planets which we have been enabled to observe have motions of rotation on axes, in times not very different from that of the earth.

107. **Figure of the earth supplies another proof.**—Besides these, it has been shown in a preceding chapter that another proof of the rotation of the earth is supplied by a peculiar departure from the strictly globular form (68).

108. **How this rotation of the earth explains the diurnal phenomena.**—We are then to conclude that the earth, being a globe, has a motion of uniform rotation round a certain diameter. The universe around it is relatively stationary, and the bodies which compose it being at distances which mere vision cannot appreciate, appear as if they were situate on the surface of a vast celestial sphere in the centre of which the earth revolves. This rotation of the earth gives to the sphere the appearance of revolving in the contrary direction, as the progressive motion of a boat on a river gives to the banks an appearance of retrogressive motion; and since the apparent motion of the heavens is from east to west, the real rotation of the earth which produces that appearance must be from west to east.

How this motion of rotation explains the phenomena of the rising and setting of celestial objects is easily understood. An observer placed at any point upon the surface of the earth is carried round the axis in a circle in twenty-four hours, so that every side of the celestial sphere is in succession exposed to his view. As he is carried upon the side opposite to that in which the sun is placed, he sees the starry heavens visible in the absence of the splendour of that luminary. As he is turned gradually towards the side where the sun is placed, its light begins to appear in the firmament, the dawn of morning is manifested, and the globe continuing to turn, he is brought into view of the luminary itself, and all the phenomena of dawn, morning, and sunrise are exhibited. While he is directed towards the side of the firmament in which the sun is placed, the other bodies of inferior lustre are lost in the splendour of that luminary, and all the phenomena of day are exhibited. When by the continued rotation of the globe the observer begins to be turned away from the direction of the sun, that luminary declines, and at

length disappears, producing all the phenomena of evening and sunset.

Such, in general, are the effects which would attend the motion of a spectator placed upon the earth's surface, and carried round with it by its motion of rotation. He is the spectator of a gorgeous diorama exhibited on a vast scale, the earth which forms his station being the revolving stage by which he is carried round, so as to view in succession the spectacle which surrounds him.

These appearances vary with the position assumed by the observer on this revolving stage, or, in other words, upon his situation on the earth, as will presently appear.

109. **The earth's axis.**—That diameter upon which it is necessary to suppose the earth to revolve in order to explain the phenomena is that which passes through the terrestrial poles.

110. **The terrestrial equator, poles, and meridians.**—If the globe of the earth be imagined to be cut by a plane passing through its centre at right angles to its axis, such a plane will meet the surface in a circle, which will divide it into two hemispheres, at the summits of which the poles are situate. This circle is called the TERRESTRIAL EQUATOR.

That hemisphere which includes the Continent of Europe is called the NORTHERN HEMISPHERE, and the pole which it includes is called the NORTHERN TERRESTRIAL POLE; the other hemisphere being the SOUTHERN HEMISPHERE, and including the SOUTHERN TERRESTRIAL POLE.

If the surface of the earth be imagined to be intersected by planes passing through its axis, they will meet the surface in circles which, passing through the poles, will be at right angles to the equator. These circles are called TERRESTRIAL MERIDIANS, and will be seen delineated on any ordinary terrestrial globe.

111. **Latitude and longitude.**—The positions of places upon the surface of the earth are expressed and indicated by stating their distance north or south of the equator, measured upon a meridian passing through them, and by the distance of such meridian east or west of some fixed meridian arbitrarily selected, such as the meridian passing through the observatory at Greenwich. The former distance, expressed in degrees, minutes, and seconds, is called the LATITUDE, and the latter, similarly expressed, the LONGITUDE of the place.

112. **Fixed meridians — those of Greenwich and Paris.**—As no natural phenomenon is found by which a fixed meridian from which longitude is measured can be determined, astronomers and geographers have not agreed in the arbitrary selection of one. The meridians of the Greenwich and Paris observatories have been taken, the former by English, and the latter by French authorities,

as the starting-point. To reduce the longitudes expressed by either to the other, it is only necessary to add or subtract the angle under the meridians of the two observatories, the most recent determination of which has been ascertained to be $2° 20' 9''.5$, the meridian of Paris being east of that of Greenwich.

113. **How the diurnal phenomena vary with the latitude.**—Let S Æ N Q, *fig.* 34, represent the earth suspended in space, surrounded at an immeasurable distance by the stellar universe. The magnitude of the earth being absolutely insignificant compared with the distances of the stars, the aspect of these will be the same

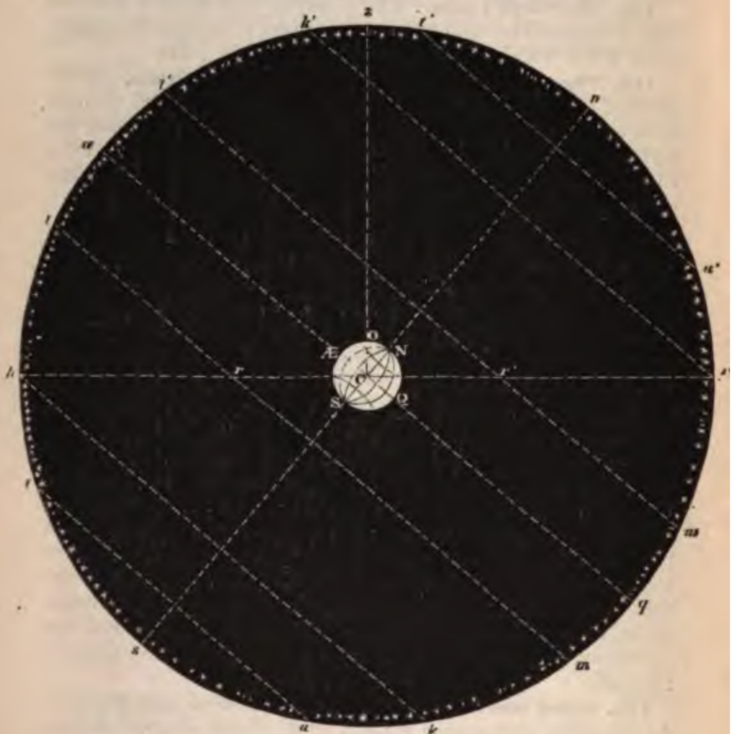

Fig. 34.

whether they are viewed from any point on its surface, or from its *centre.* The observer may therefore, whatever be his position on

the earth, be considered as looking from the centre of the celestial sphere.

Let us suppose, in the first place, the observer to be at O, a point on its surface between the equator Æ and the north pole N, the latitude of which will therefore be O Æ, and will be measured by the angle O C Æ. If a line be imagined to be drawn from the centre C through the place O of the observer, and continued upwards to the firmament, it will arrive at the point *z*, which is the zenith of the observer. If the terrestrial axis S N be imagined to be continued to the firmament, it will arrive at the north celestial pole *n* and the south celestial pole *s*. If the plane of the terrestrial equator Æ Q be supposed to be continued to the heavens, it will intersect the surface of the celestial sphere at the celestial equator *æ q*.

The observer placed at O will see the entire hemisphere *h z h'* of which his zenith *z* is the summit; and the other hemisphere *h s h'* will be invisible to him, being in fact concealed from his view by the earth on which he stands.

It is evident that the arc of the heavens *z n* between his zenith and the north celestial pole consists of the same number of degrees as the arc O N of the terrestrial meridian between his place of observation O and the north terrestrial pole *n*. The zenith distance therefore of the visible pole at any place is always equal to the actual distance expressed in degrees of that place from the terrestrial pole, and as this distance is the COMPLEMENT * OF THE LATITUDE, it follows that the zenith distance of the visible pole is the complement of the latitude, and that the altitude of the visible pole is equal to the latitude of the place.

114. **Method of finding the latitude of the place.** — The latitude of the place of observation may therefore be always determined if the altitude of the celestial pole can be observed. If there were any star situate precisely at the pole, it would therefore be sufficient to observe its altitude. There is, however, no star exactly at the pole, although, as has been already observed, the POLE STAR is very near it. The altitude of the pole is found, therefore, not by one, but by two observations. The pole star, or any other star situate near the pole, is carried round it in a circle by the apparent diurnal motion of the sphere, and it necessarily crosses the meridian twice in each revolution, once *above*, and once *below* the pole. Its altitude in the latter position is the *least*, and in the former the *greatest* it ever has; and the pole itself is just midway between these two extreme positions of this circumpolar star. To find the actual altitude of the pole, it is only necessary therefore to take the *mean*, that is,

* The complement of an angle or arc is that number of degrees by which it differs from 90°. Thus 30° is the complement of 60°.

half the sum of these two extreme altitudes. By making the same observations with several circumpolar stars, and taking a mean of the whole, still greater accuracy may be attained.

115. **Position of celestial equator and poles varies with the latitude.**— Since the altitude of the celestial pole is everywhere equal to the latitude of the place, and since the position of the celestial equator and its parallels in which all celestial objects appear to be moved by the diurnal rotation, varies with that of the pole, it is evident that the celestial sphere must present a different appearance to the observer at every different latitude. In proceeding towards the terrestrial pole, the celestial pole will gradually approach the zenith, until we arrive at the terrestrial pole, when it will actually coincide with that point; and in proceeding towards the terrestrial equator the celestial pole will gradually descend towards the horizon, and on arriving at the Line it will be actually on the horizon.

116. **Parallel sphere seen at the poles.**—At the poles, therefore, the celestial pole being in the zenith, the celestial equator will coincide with the horizon, and by the diurnal motion all objects will move in circles parallel to the horizon. Every object will therefore preserve during twenty-four hours the same altitude and the same zenith distance. No object will either rise or set, at least so far as the diurnal motion is concerned.

This aspect of the firmament is called a PARALLEL SPHERE, the motion being parallel to the horizon.

117. **Right sphere seen at the equator.**—At the terrestrial equator, the poles being upon the horizon, the axis of the celestial sphere will coincide with a line drawn upon the plane of the horizon connecting the north and south points. The celestial equator and its parallels will be at right angles to the plane of the horizon; and since the plane of the horizon passes through the centre of all the parallels, it will divide them all into equal semicircles.

It follows, therefore, that all objects on the heavens will be equal times above and below the horizon, and that they will rise and set in planes perpendicular to the horizon.

This aspect of the firmament is called a RIGHT SPHERE, the diurnal motion being at right angles to the horizon.

118. **Oblique sphere seen at intermediate latitudes.**—At latitudes between the equator and pole, the celestial pole holds a place between the horizon and the zenith determined by the latitude. The celestial equator *æ q*, *fig.* 34, and its parallels, are inclined to the plane of the horizon at angles equal to the distance of the pole from the zenith, and therefore equal to the complement of the latitude. The centres of all parallels to the celestial equator *æ q* which are between it and the visible pole are above the plane of the

horizon, between C and N, and the centres of all parallels at the other side of the equator below it. The parallels, such as l' m' and l m, will therefore be all divided unequally by the plane of the horizon, the visible part l' r' being greater than the invisible part m' r' for the former, and the invisible part m r greater than the visible part l r for the latter.

It follows, therefore, that all objects between the celestial equator $æ$ q and the visible pole N will be longer above than below the horizon, and all objects on the other side of the equator will be longer below the horizon than above it.

A parallel h' k' to the celestial equator, whose distance from the visible pole is equal to the latitude, will be entirely above the horizon, just touching it at the point under the visible pole; and a corresponding parallel h k, at an equal distance from the invisible pole, will be entirely below the horizon, just touching it at the point above the invisible pole.

All parallels nearer to the visible pole than h' k' will be entirely above the horizon, and all parallels nearer to the invisible pole than h k will be entirely below it.

Hence it is that, in European latitudes, stars within a certain limited distance of the north or visible celestial pole never set, and stars at a corresponding distance from the south or invisible celestial pole never rise.

The observer can only see these by going to places of observation having lower latitudes.

This aspect of the firmament is called an OBLIQUE SPHERE, the diurnal motion being oblique to the horizon.

119. **Objects in celestial equator equal times above and below horizon.** — Whether the sphere be right or oblique, the centre of the celestial equator being on the plane of the horizon, one half of that circle will be below, and the other above the horizon. Every object upon it will therefore be equal times above and below the horizon, rising and setting exactly at the east and west points.

In the parallel sphere, the celestial equator coinciding with the horizon, an object upon it will be carried round the horizon by the diurnal rotation, without either rising or setting.*

120. **Method of determining the longitude of places.** — This perfect uniformity of the earth's rotation, inferred from the

* The teacher will find it advantageous to exercise the student in the subject of the preceding paragraphs, aided by an armillary sphere, or, if that be not accessible, by a celestial globe, which will serve nearly as well. Many questions will suggest themselves, arising out of and deducible from what has been explained above, with respect to the various altitudes of the sphere in different latitudes.

observed uniformity of the apparent rotation of the firmament, is the basis of all methods of determining the longitude. The longitude of a place will be determined if the angle under the meridian of the place, and that of any other place whose longitude is known, can be found. But since, by the uniform rotation of the globe, the meridians of all places upon it are brought in regular succession under every part of the firmament, the moments at which the two meridians pass under the same star, or, what is the same, the moments at which the same star is seen to pass over the two meridians, being observed, the interval will bear the same ratio to the entire time of the earth's rotation as the difference of the longitudes of the two places bears to 360°.

To make this more clear, let us take the case of two places P and P′, *fig.* 35, upon the equator. If C be the centre of the earth, the angle P C P′ will be the difference between the longitudes. Now, let the time be observed at each place at which any particular star S is seen upon the meridian. If the motion of the earth be in the direction of the arrow, the meridian of P will come to the star before the meridian of P′. This necessarily supposes P to be east of P′, since the earth revolves from west to east. Let the true interval of time between the passage of S over the two meridians be t, let T be the time of one complete revolution of the globe on its axis, and let L be the difference of the longitudes, or the angle P C P′; we shall then have

Fig. 35.

$$t : \text{T} :: \text{L} : 360°,$$

$$\text{L} = \frac{t}{\text{T}} \times 360°.$$

But in the practical solution of this problem a difficulty is presented which has conferred historical celebrity upon the question, and caused it to be referred to as the type of all difficult enquiries. It is supposed, in what has just been explained, that means are provided at the two places P and P′ by which the absolute moments of the transit of the star over the respective meridians may be ascertained, so as to give the exact interval between them. If these times of transit be observed by any form of chronometer, it would then be necessary that the two chronometers should be in exact accordance, or, what is the same, that their exact difference may be known. If a chronometer, set correctly by another which is stationary at one place P, be transported to the other place P′, this object will be

attained, subject, however, to the error which may be incidental to the rate of the chronometer thus transported. If the distance between the places be not considerable, the chronometers may thus be brought into very exact accordance; but when the distance is great, and that a long interval must elapse during the transport of the chronometer, this expedient is subject to errors too considerable to be tolerated in the solution of a problem of such capital importance.*

It will be apparent that the real object to be attained is to find some phenomenon sufficiently instantaneous in its manifestation to mark, with all the necessary precision, a certain moment of time. Such a phenomenon would be, for example, the sudden extinction of a conspicuous light seen at once at both places. The moment of such a phenomenon being observed by means of two chronometers at the places, the difference of the times indicated by them would be known, and they would then serve for the determination of the difference of the longitudes by the method explained above. Several phenomena, both terrestrial and celestial, have accordingly been used for this purpose. Among the former may be mentioned the sudden extinction of the oxyhydrogen or electric light, the explosion of a rocket, &c.; among the latter, the extinction of a star by the disk of the moon passing over it, and the eclipses of the satellites of Jupiter, phenomena which will be more fully noticed hereafter.

121. **Lunar method of finding the longitude.** — The change of position of the moon with relation to the sun and stars being very rapid, affords another phenomenon which has been found of great utility in the determination of the longitude, especially for the purposes of mariners. Tables are calculated in which the moon's apparent distances from the sun, and many of the most conspicuous fixed stars, are given for short intervals of time, and the exact times at Greenwich when the moon has these distances are given. If then the mariner, observing with proper instruments the position of the moon with relation to these objects, compares his observed distances with the tables which are supplied to him in the Nautical Almanac, he will find the time at Greenwich corresponding to the moment of his observation; and being always, by the ordinary methods, able to determine by observation the local time at the place of his observation, the difference gives him the time required for a star to pass from the meridian of Greenwich to

* During the determination of the longitude of the island of Valencia, on the western coast of Ireland, in the year 1844, which was performed by transporting a considerable number of chronometers between Greenwich and that island, it was found that the effect of travelling on pocket chronometers, carefully packed, was to cause them to lose $0^s.7$ per day over their stationary rates.

the meridian of the place of his observation, or *vice versâ;* and this time gives the longitude, as already explained.

This last is known as the LUNAR METHOD OF DETERMINING THE LONGITUDE.

In practice, many details are necessary, and various calculations must be made, which cannot be explained here.

122. **Method by the electric telegraph.**—The determination of differences of longitude by the aid of galvanism, when the two observing stations are connected by a line of electric telegraph, has been generally adopted since the year 1853, not only for the simplicity of the method of observation, but for the great accuracy of the result obtained. A galvanic signal is transmitted from one station to the other, causing a simultaneous deflection of a magnetic needle at the two stations, the exact instant of which is recorded by an observer. These signals are generally continued through an interval of time previously agreed upon, which in most cases is one hour. To destroy the effect of a constant error arising from the retardation of the galvanic current, which would result if all the signals were sent from one station, it is the general rule that during the first quarter of an hour the signals are made at one station, as at Greenwich for instance; during the second quarter they are transmitted from the other station, such as Paris; in the third quarter, Greenwich would signal; and in the last, the signals would be received from Paris.

The true sidereal time at which the signal was observed is found by carefully determining the error of the clock by transits of a series of special stars which are observed if possible at the two observatories. The difference of longitude is thus easily obtained by simply taking the difference between the sidereal times corresponding to the respective signals observed at the two stations.

In observatories which have adopted the chronographic method of recording transits, the results may be made still more accurate by a simultaneous registration of the galvanic signals on the apparatus at both stations. Owing, however, to the difficulty of obtaining a proper apparatus, this method has not yet been generally used, though a successful determination of the difference of longitude between Greenwich and Edinburgh has been made.

123. **Parallels of latitude.**—A series of points on the earth which are at equal distances from the equator, or which have the same latitude, form a circle parallel to the equator, called a PARALLEL OF LATITUDE.

Thus all places which have the same latitude are on the same parallel.

All places which are on the same meridian have the same longitude.

CHAPTER VII.

ANNUAL MOTION OF THE EARTH.

124. **Apparent motion of the sun in the heavens.**—Independently of the motion which the sun has in common with the entire firmament, and in virtue of which it rises, ascends to the meridian, and sets, it is observed to change its position from day to day with relation to the other celestial objects among which it is placed. In this respect, therefore, it differs essentially from the stars, which maintain their relative positions for months, years, and ages, unaltered.

If the exact position of the sun be observed from day to day and from month to month, through the year, with reference to the stars, it will be found that it has an apparent motion among them in a great circle of the celestial sphere, the plane of which forms an angle of 23° 28′ with the plane of the celestial equator.

125. **Ascertained by the transit instrument and mural circle.**—This apparent motion of the sun was ascertained with considerable precision before the invention of the telescope and the subsequent and consequent improvement of the instruments of observation. It may, however, be made more clearly manifest by the transit instrument and mural circle.

If the transit of the sun be observed daily (28), and its right ascension be ascertained (31), it will be found that from day to day the right ascension continually increases, so that the circle of declination (30) passing through the centre of the sun is carried with the sun round the heavens, making a complete revolution in a year, and moving constantly from west to east, or in a direction contrary to the apparent diurnal motion of the firmament.

If the point at which the sun's centre crosses the meridian daily be observed with the mural circle (34), it will be found to change from day to day. Let its distance from the celestial equator, or its declination, be observed (41) daily at noon. It will be found to be nothing on the 21st of March and 21st of September, on which days the polar distance of the sun's centre will be therefore 90°. The sun's centre is, then, on these days, in the celestial equator. After the 21st of March the sun's centre will be north of the equator, and its declination will continually increase, until it becomes 23° 28′ on the 21st of June. It will then begin slowly to decrease, and will continue to decrease until the 21st of September, when the centre of the sun will again be in the equator. After that it will pass the meridian south of the equator, and will consequently have south declination. This will increase, until it becomes 23° 28′

on the 21st of December; after which it will decrease until the centre of the sun returns to the equator on the 21st of March.

By ascertaining the position of the centre of the sun's disk from day to day, by means of its right ascension and declination (42), and tracing its course upon the surface of a celestial globe, its path is proved to be a great circle of the heavens, inclined to the equator at an angle of $23° 28'$.

126. **The ecliptic.**—This great circle in which the centre of the disk of the sun thus appears to move, completing its revolution in it in a year, is called the ECLIPTIC, because solar and lunar eclipses can never take place except when the moon is in or very near it.

127. **The equinoxial points.**—The ecliptic intersects the celestial equator at two points diametrically opposite to each other, dividing the equator, and being divided by it into equal parts. These are called the EQUINOXIAL POINTS, because, when the centre of the solar disk arrives at them, being then in the celestial equator, the sun will be equal times above and below the horizon (119), and the days and nights will be equal.

128. **The vernal and autumnal equinoxes.**—The equinoxial point at which the sun passes from the south to the north of the celestial equator is called the VERNAL, and that at which it passes from the north to the south is called the AUTUMNAL, equinoxial point. The TIMES at which the centre of the sun is found at these points are called, respectively, the VERNAL and AUTUMNAL EQUINOXES.

The vernal equinox, therefore, takes place on the 21st of March, and the autumnal on the 21st of September.

129. **The seasons.**—That semicircle of the ecliptic through which the sun moves from the vernal to the autumnal equinox is north of the celestial equator; and during that interval the sun will therefore be longer above than below the horizon, and will pass the meridian above the equator in places having north latitude. The days, therefore, during that half-year will be longer than the nights.

That semicircle through which the centre of the sun moves from the autumnal to the vernal equinox being south of the celestial equator, the sun, for like reasons, will during that half-year be longer below than above the horizon, and the days will be shorter than the nights, the sun rising to a point of the meridian below the equator.

The three months which succeed the vernal equinox are called SPRING, and those which precede it WINTER; the three months which precede the autumnal equinox are called SUMMER, and those which succeed it AUTUMN.

130. The solstices.—Those points of the ecliptic which are midway between the equinoxial points are the most distant from the celestial equator. The arcs of the ecliptic between these points and the equinoxial points are therefore 90°. These are called the SOLSTITIAL POINTS, and the times at which the centre of the solar disk passes through them are called the SOLSTICES.

The summer solstice, therefore, takes place on the 21st of June and the winter solstice on the 21st of December.

This distance of the summer solstitial point north, and of the winter solstitial point south of the celestial equator is 23° 28′.

The more distant the centre of the sun is from the celestial equator, the more unequal will be the days and nights (108), and consequently the longest day will be the day of the summer solstice, and the shortest the day of the winter solstice.

It will be evident that the seasons must be reversed in southern latitudes, since there the visible celestial pole will be the south pole. The summer solstice and the vernal equinox of the northern, are the winter solstice and autumnal equinox of the southern hemisphere. Nevertheless, as the most densely inhabited and civilised parts of the globe are in the northern hemisphere, the names in reference to the local phenomena are usually preserved.

131. The zodiac.—The apparent motions of the planets are included within a space of the celestial sphere extending a few degrees north and south of the ecliptic. The zone of the heavens included within these limits is called the ZODIAC.

132. The signs of the zodiac.—The circle of the zodiac is divided into twelve equal parts, called SIGNS, each of which therefore measures 30°. They are named from principal constellations, or groups of stars, which are placed in or near them. Beginning from the vernal equinoxial point they are as follows:—

	Sign.		Sign.
1. Aries (the ram)	♈	7. Libra (the balance)	♎
2. Taurus (the bull)	♉	8. Scorpio (the scorpion)	♏
3. Gemini (the twins)	♊	9. Sagittarius (the archer)	♐
4. Cancer (the crab)	♋	10 Capricornus (the goat)	♑
5. Leo (the lion)	♌	11 Aquarius (the waterman)	♒
6. Virgo (the virgin)	♍	12. Pisces (the fishes)	♓

Thus, the position of the vernal equinoxial point is the FIRST POINT OF ARIES, and that of the autumnal the FIRST POINT OF LIBRA. The summer solstitial point is at the FIRST POINT OF CANCER, and the winter at the FIRST POINT OF CAPRICORN.

133. The tropics.—The points of the ecliptic at which the centre of the sun is most distant from the celestial equator are also called the TROPICS,—the northern being the TROPIC OF CANCER, and the southern the TROPIC OF CAPRICORN.

This term TROPIC is also applied in geography to those parts of the earth whose distances from the terrestrial equator are equal to the greatest distance of the centre of the solar disk from the celestial equator. The NORTHERN TROPIC is, therefore, a parallel of latitude 23° 28′ north, and the SOUTHERN TROPIC a parallel of latitude 23° 28′ south of the terrestrial equator.

134. **Celestial latitude and longitude.**—The terms latitude and longitude, as applied to objects on the heavens, have a signification different from that given to them when applied to places upon the earth. The latitude of an object on the heavens means its distance from the ecliptic, measured in a direction perpendicular to the ecliptic; and its longitude is the arc of the ecliptic, between the first point of Aries and the circle which measures its latitude, taken, like the right ascension, according to the order of the signs.

Thus since the centre of the sun is always on the ecliptic, its latitude is always 0°. At the vernal equinox its longitude is 0°, at the summer solstice it is 90°, at the autumnal equinox 180°, and at the winter solstice 270°.

135. **Annual motion of the earth.**—The apparent annual motion of the sun, described above, is a phenomenon which can only proceed from one or other of two causes. It may arise from a real annual revolution of the sun round the earth at rest, or from a real revolution of the earth round the sun at rest. Either of these causes would explain, in an equally satisfactory manner, all the circumstances attending the apparent annual motion of the sun around the firmament. There is nothing in the appearance of the sun itself which could give a greater probability to either of these hypotheses than to the other. If, therefore, we are to choose between them, we must seek the grounds of choice in some other circumstances.

It was not until the revival of letters that the annual motion of the earth was admitted. Its apparent stability and repose were until then universally maintained. An opinion so long and so deeply rooted must have had some natural and intelligible grounds. These grounds, undoubtedly, are to be found only in the general impression, that if the globe moved, and especially if its motion had so enormous a velocity as must be imputed to it, on the supposition that it moves annually round the sun, we must in some way or other be sensible of such movement.

All the reasons, however, why we are unconscious of the real rotation of the earth upon its axis (102) are equally applicable to show why we must be unconscious of the progressive motion of the earth in its annual course round the sun. The motion of the globe through space being perfectly smooth and uniform, we can have no sensible means of knowing it, except those which we possess in the case of a boat moving smoothly along a river: that is, by

looking abroad at some external objects which do not participate in the motion imputed to the earth. Now, when we do look abroad at such objects, we find that they appear to move exactly as stationary objects would appear to move, seen from a movable station. It is plain, then, if it be true that the earth really has the annual motion round the sun which is contended for, that we cannot expect to be conscious of this motion from anything which can be observed on our own bodies or those which surround us on the surface of the earth: we must look for it elsewhere.

But it will be contended that the apparent motion of the sun, even upon the argument just stated, may equally be explained by the motion of the earth round the sun, or the motion of the sun round the earth; and that, therefore, this appearance can still prove nothing positively on this question. We have, however, other proofs, of a very decisive character.

Newton showed that it was a general law of nature, and part, in fact, of the principle of gravitation, that any two globes placed at a distance from each other, if they are in the first instance quiescent and free, must move with an accelerated motion to their common centre of gravity, where they will meet and coalesce; but if they be projected in a direction not passing through this centre of gravity, they will both of them revolve in orbits around that point periodically.

Now the common centre of gravity of the earth and sun, owing to the immense preponderance of the mass of the sun (M.309), is placed at a point very near the centre of the sun. Round that, point, therefore, the earth must, according to this principle, revolve.

136. **Motion of light proves the annual motion of the earth.** —Since the principle of gravitation itself might be considered as more or less hypothetical, it has been considered desirable to find other independent and more direct proofs of a phenomenon, so fundamentally important and so contrary to the first impressions of mankind, as the revolution of the earth and the quiescence of the sun. A remarkable evidence of this motion has been accordingly discovered in a vast body of apparently complicated phenomena which are the immediate effects of such a motion, which could not be explained if the earth were at rest and the sun in motion, and which would be inexplicable on any other supposition save the revolution of the earth round the sun.

It has been ascertained that light is propagated through space with a certain great but definite velocity of about 184,000 miles per second. That light has this velocity is proved by the body of optical phenomena which cannot be explained without imputing to it such a motion, and which are perfectly explicable if such a

motion be admitted. Independently of this, another demonstration that light moves with this velocity is supplied by an astronomical phenomenon which will be noticed in a subsequent part of this volume.

137. **Aberration of light.** — Assuming, then, the velocity of light, and that the earth is in motion in an orbit round the sun with a velocity of about 19 miles per second, which must be its speed if it move at all, as will hereafter appear, an effect would be produced upon the apparent places of all celestial objects by the combination of these two motions which we shall now explain.

It has been stated that the apparent direction of a visible object is the direction from which the visual ray enters the eye. Now this will depend on the actual direction of the ray, if the eye which receives it be quiescent; but if the eye be in motion, the same effect is produced upon the organ of sense as if the ray, besides the motion which is proper to it, had another motion equal and contrary to that of the eye. Thus, if light moving from the north to the south with a velocity of 184,000 miles per second be struck by an eye moving from west to east with the same velocity, the effect produced by the light upon the organ will be the same as if the eye, being at rest, were struck by the light having a motion compounded of two equal motions, one from north to south, and the other from east to west. The direction of this compound effect would, by the principles of the composition of motion (M. 172), be equivalent to a motion from the direction of the north-east. The object from which the light comes would, therefore, be apparently displaced, and would be seen at a point beyond that which it really occupies in the direction in which the eye of the observer is moved. This displacement is called accordingly the ABERRATION OF LIGHT.

This may be made still more evident by the following mode of illustration. Let O, *fig.* 36, be the object from which light comes in the direction O o e''. Let e be the place of the eye of the observer when the light is at o, and let the eye be supposed to move from e to e'' in the same time that the light moves from o to e''. Let a straight tube be imagined to be directed from the eye at e to the light at o, so that the light shall be in the centre of its opening, while the tube moves with the eye from o e to o'' e'' maintaining constantly the same direction, and remaining parallel to itself: the light in moving from o to e'', will pass along its axis, and will arrive at e'' when the eye arrives at that point. Now it is evident that in this case the direction in which the object would be visible, would be the direction of the axis of the tube, so that, instead of appearing in the direction o O, which is its true direction, it would appear in the direction o O′ advanced from O in the direction of the motion e e'' with which the observer is affected.

The motion of light being at the rate of 184,000 miles per second, and that of the earth (if it move at all) at the rate of 19 miles per second, it follows, that the proportion of $o\,e''$ to $e\,e''$ must be 184,000 to 19, or 10,200 to 1.

The ANGLE OF ABERRATION $o\,o\,o'$ will vary with the obliquity of the direction $e\,e''$ of the observer's motion to that of the visual ray $o\,e''$. In all cases the ratio of $o\,e''$ to $e\,e''$ will be 10,200 to 1. If the direction of the earth's motion be at right angles to the direction $o\,e''$ of the object o, we shall have the aberration equal to $20''\cdot44$.

If the angle $o\,e''\,e$ be oblique, it will be necessary to reduce $e\,e''$ to its component at right angles to $o\,e''$, which is done by multiplying it by the trigonometrical sine of the obliquity $o\,e''\,e$ of the direction of the object to that of the earth's motion.

According to this, the aberration would be greatest when the direction of the earth's motion is at right angles to that of the object, and would decrease as the angle of obliquity decreases, being nothing when the object is seen in the direction in which the earth is moving, or in exactly the contrary direction.


Fig. 36.

The phenomena may also be imagined by considering that the earth, in revolving round the sun, constantly changes the direction of its motion; that direction making a complete revolution with the earth, it follows that the effect produced upon the apparent place of a distant object would be the same as if that object really revolved once in a year round its true place in a circle whose plane would be parallel to that of the earth's orbit, and whose radius would subtend at the earth an angle of $20''\cdot42$, and the object would be always seen in such a circle 90° in advance of the earth's place in its orbit.

These circles would be reduced by projection to ellipses of infinitely various excentricities, according to the position of the object with relation to the plane of the earth's orbit. At a point perpendicularly above that plane, the object would appear to move annually in an exact circle. At points nearer to the ecliptic, its apparent path would be an ellipse, the excentricity of which would increase as the distance from the ecliptic would diminish, according to definite conditions.

Now, all these apparent motions are actually observed to affect

all the bodies visible on the heavens, and to affect them in precisely the degree and direction which would be produced by the annual motion of the earth round the sun.

As the supposed motion of the earth round the sun completely and satisfactorily explains this complicated body of phenomena called aberration, while the motion of the sun round the earth would altogether fail to explain them, they afford another striking evidence of the annual motion of the earth.

138. **Argument from analogy.**—Another argument in favour of the earth's annual motion round the sun is taken from its analogy to the planets, to all of which, like the earth, the sun is a source of light and heat, and all of which revolve round the sun as a centre, having days, nights, and seasons in all respects similar to those which prevail upon the earth. It seems, therefore, contrary to all probability, that the earth alone, being one of the planets, and by no means the greatest in magnitude or physical importance, should be a centre round which not only the sun, but all the other planets, should revolve.

139. **The diurnal and annual phenomena explained by the two motions of the earth.**—Considering, then, the annual revolution of the earth, as well as its diurnal rotation, established, it remains to show how these two motions will explain the various phenomena manifested in the succession of seasons.

Fig. 37.

Fig. 38.

While the earth revolves annually around the sun, it has a motion of rotation at the same time upon a certain diameter as an axis, which is inclined from the perpendicular to its orbit at the angle of $23° 28'$. During the annual motion of the earth this diameter keeps continually parallel to the same direction, and the earth completes its revolution upon it in twenty-three hours and fifty-six minutes. In consequence of the combination of this motion of rotation of the earth upon its axis with its annual motion around the sun, we are supplied with the alternations of day and night, and the succession of seasons.

When the globe of the earth is in such a position that its north

pole is turned towards the sun, the greater portion of its northern hemisphere is enlightened, and the greater portion of the southern hemisphere is dark. This position is represented in *fig.* 37, where N is the north pole, and S the south pole. The days are therefore longer than the nights in the northern hemisphere. The reverse is the case with the southern hemisphere, for there the greater segments of the parallels are dark, and the lesser segments enlightened; the days are therefore shorter than the nights. Upon the equator, however, at Æ, the circle of the earth is equally divided, and the days and nights are equal. When the south pole is turned towards the sun, which it does exactly at the opposite point of the earth's annual orbit, circumstances are reversed; then the days are longer than the nights in the southern hemisphere, and the nights are longer than the days in the northern hemisphere. At the intermediate points of the earth's annual path, when the axis assumes a position perpendicular to the direction of the sun, *fig.* 38, then the circle of light and darkness passes through the poles; all parallels in every part of the earth are equally divided, and there is consequently equal day and night all over the globe.

In the annexed perspective diagram, *fig.* 39, these four positions of the earth are exhibited in such a manner as to be clearly intelligible.

Fig. 39.

In this diagram, the observer is supposed to view the earth from the north side of the ecliptic, therefore, on the 21st of June, the north or upper pole is turned in the direction of the sun; on the 21st of December, the south or lower pole is turned in that direction. On the days of the equinoxes, the axis of the earth is at right angles to the direction of the sun, and it is equal day and night everywhere on the earth.

The annual variation of the position of the sun with reference to the equator, or the changes of its declination, are explained by these motions. The summer solstice—the time when the sun's distance from the equator is the greatest—takes place when the north pole is turned towards the sun; and the winter solstice—or the time when the sun's distance south of the equator is greatest—takes place when the south pole is turned toward the sun.

In virtue of these motions, it follows that the sun is twice a year vertical at all places between the tropics; and at the tropics themselves it is vertical once a year. In all higher latitudes the point at which the sun passes the meridian daily alternately approaches to and recedes from the zenith. From the 21st of December until the 21st of June, the point continually approaches the zenith. It comes nearest to the zenith on the 21st of June; and from that day until the 21st of December, it continually recedes from the zenith, and attains its lowest position on the latter day. The difference, therefore, between the meridional altitudes of the sun on the days of the summer and winter solstices at all places will be twice twenty-three degrees and twenty-eight minutes, or forty-six degrees and fifty-six minutes. In all places beyond the tropics in the northern hemisphere, therefore, the sun rises at noon on the 21st of June, forty-six degrees and fifty-six minutes higher than it rises on the 21st of December. These are the limits of meridional altitude which determine the influence of the sun in different places.

140. **Mean solar or civil time.**—It has been explained that the rotation of the earth upon its axis is rigorously uniform, and is the only absolutely uniform motion among the many and complicated motions observable on the heavens. This quality would render it a highly convenient measure of time, and it is accordingly adopted for that purpose in all observatories. The hands of a sidereal clock move in perfect accordance with the apparent motion of the firmament.

But for civil purposes, uniformity of motion is not the only condition which must be fulfilled by a measure of time. It is equally indispensable that the intervals into which it divides duration should be marked by conspicuous and universally observable phenomena. Now it happens that the intervals into which the diurnal revolution of the heavens divides duration, are marked by phenomena which astronomers alone can witness and ascertain, but of which mankind in general are, and must remain, altogether unconscious.

141. **Civil day — noon and midnight.—Astronomical day.**—For the purposes of common life, mankind by general consent has therefore adopted the interval between the successive returns of the centre of the sun's disk to the meridian, as the unit or standard

measure of time. This interval, called a CIVIL DAY, is divided into 24 equal parts called HOURS, which are again subdivided into minutes and seconds, as already explained in relation to sidereal time. The hours of the civil day, however, are not generally counted from 0 to 24 as in sidereal time, but are divided into two equal parts of 12 hours, one commencing when the centre of the sun is on the meridian, the moment of which is called NOON or MIDDAY, and the other 12 hours later when the centre of the sun must pass the meridian below the horizon, the moment of which is MIDNIGHT.

For civil purposes, this latter moment has been adopted as the commencement of one day, and the end of the other.

In observatories, and for astronomical convenience generally, the day commences at noon, and ends at the succeeding noon, the hours being counted from 0^h to 24^h. This mode of reckoning is called an ASTRONOMICAL DAY.

142. **Difference between mean solar and sidereal time.**—A solar day is evidently longer than a sidereal day. If the sun did not change its position on the firmament, its centre would return to the meridian after the same interval that elapses between the successive transits of a fixed star. But since the sun, as has been explained, moves at the rate of about $1°$ per day from west to east, and since this motion takes place upon the ecliptic, which is inclined to the equator at an angle of $23° 28'$, the centre of the sun increases its right ascension from day to day, and this increase varies according to its position on the ecliptic. When the circle of declination on which the centre of the sun is placed at noon on one day returns to the meridian the next day, the centre of the sun will have left it, and will be found upon another circle of declination to the east of it; and it will not consequently come to the meridian until a few minutes later, when this other circle of declination, by the diurnal motion of the heavens, shall come to coincide with the meridian.

Hence the solar day is longer than the sidereal day.

143. **Difference between apparent noon and mean noon.**—But since, from the cause just stated and another which will be presently explained, the daily increase of the sun's right ascension is variable, the difference between a sidereal day and the interval between the successive transits of the sun is likewise variable, and thus it would follow that the solar days would be more or less unequal in length.

144. **Mean solar time — Equation of time.**—Hence has arisen an expedient adopted for civil purposes to efface this inequality. An imaginary sun is conceived to accompany the true sun, making the complete revolution of the heavens with a rigorously uniform increase of right ascension from hour to hour, while the increase of right ascension of the true sun thus varies. The

time measured by the motion of this imaginary sun is called MEAN SOLAR TIME, and the time measured by the motion of the true sun is called APPARENT SOLAR TIME.

The difference between the apparent and mean solar time is called the "EQUATION OF TIME."

The variation of the increase of the sun's right ascension being confined within narrow limits, the true and imaginary suns can never be far asunder, and consequently the difference between mean and apparent time is never considerable.

The time indicated by a sun-dial is apparent time, that indicated by an exactly regulated clock or watch is mean time.

The correction to be applied to apparent time, to reduce it to mean time is often engraved on sun-dials, where it is stated how much "the sun is too fast or too slow."

145. **Distance of the sun.**—Although the problem to determine with the greatest practicable precision the distance of the sun from the earth is attended with great difficulties, many phenomena of easy observation supply the means of ascertaining that this distance must bear a very great proportion to the earth's diameter, or must be such that, by comparison with it, a line 8000 miles in length is almost a point. If, for example, the apparent distance of the centre of the sun from any fixed star be observed simultaneously from two places upon the earth, no matter how far they are apart, no difference will be discovered between them, unless means of observation susceptible of extraordinary precision be resorted to. However, it may be stated here that the apparent diameter of the earth as viewed from the sun amounts to no more than $17''\cdot 9$, or about the 108th part of the apparent diameter of the sun as seen from the earth. The distance of the sun is equal to about 11,535 diameters of the earth, and amounts therefore to nearly NINETY-ONE AND A HALF MILLIONS OF MILES.

146. **Orbit of the earth elliptical.**—In what precedes, we have considered the path of the earth around the sun, called by astronomers its ORBIT, to be a circle, in the centre of which the centre of the sun is placed. This is nearly true, but not exactly so, as will appear from the following observed phenomena.

Let a telescope supplied with micrometric wires be directed to

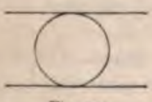

Fig. 40.

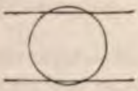

Fig. 41.

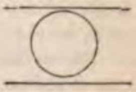

Fig. 42.

the sun, and the wires so adjusted that they shall exactly touch the upper and lower limbs, as in *fig.* 40. Let the observer then

watch from day to day the appearance of the sun and the position of the wires; he will find that, after a certain time, the wires will no longer touch the sun, but will perhaps fall a little within it, as represented in *fig.* 41. And after a further lapse of time he will find, on the other hand, that they fall a little without it, as in *fig.* 42.

Now, as the wires throughout such a series of observations are maintained always in the same position, it follows that the disk of the sun must appear smaller at one time, and larger at another—that, in fact, the apparent magnitude of the sun must be variable. It is true that this variation is confined within very small limits, but still it is distinctly perceptible. What, then, it may be asked, must be its cause? Is it possible to imagine that the sun *really undergoes a change in its size?* This idea would, under any circumstances, be absurd; but when we have ascertained, as we may do, that the change of apparent magnitude of the sun is regular and periodical—that for one half of the year it continually diminishes until it attains a minimum, and then for the next half year it increases until it attains a maximum—such a supposition as that of a real periodical change in the globe of the sun becomes altogether incredible.

If, then, an actual change in the magnitude of the sun be impossible, there is but one other conceivable cause for the change in its apparent magnitude—which is, a corresponding change in the earth's distance from it. If the earth at one time be more remote than at another, the sun will appear proportionally smaller. This is an easy and obvious explanation of the changes of appearance that are observed, and it has been demonstrated accordingly to be the true one.

On examining the change of the apparent diameter of the sun, it is found that it is least on the 1st of July, and greatest on the 31st of December; that from December to July, it regularly decreases; and from July to December, it regularly increases.

Since the distance of the earth from the sun must increase in the same ratio as the apparent diameter of the sun decreases, and *vice versâ* (O.351), the variation of the distance of the earth from the sun in every position which it assumes in its orbit can be exactly ascertained. A plan of the form of the orbit may therefore be laid down, having the point occupied by the centre of the sun marked in it. Such a plan proves on geometric examination to be an ellipse, the place of the sun being one of the foci.

147. **Method of describing an ellipse—its foci, axis, and excentricity.**—If the ends of a thread be attached to two points less distant from each other than its entire length, and a pencil be looped in the thread, and moved round the points, so as to keep the thread tight, it will trace an ellipse, of which the two points are the FOCI.

The line drawn joining the foci, continued in both directions to the ellipse, is called its TRANSVERSE, or MAJOR AXIS.

Another line, passing through the middle point of this at right angles to it is called its MINOR AXIS.

Fig. 43.

The middle point of the major axis is called the CENTRE of the ellipse.

The fractional or decimal number which expresses the distance of the focus from the centre, the semiaxis major being taken as the unit, is called the excentricity of the ellipse.

In *fig.* 43, C is the centre, S and S′ the foci, A B the transverse axis.

The less the ratio of S S′ to A B, or what is the same, the less the excentricity is, the more nearly the form of the ellipse approaches to that of a circle, and when the foci actually coalesce, the ellipse becomes an exact circle.

148. **Excentricity of the earth's orbit.**—The excentricity of the elliptic orbit of the earth is so small, that if an ellipse, representing truly that orbit, were drawn upon paper, it would be distinguishable from a circle only by submitting it to exact measurement. The excentricity of the orbit has been ascertained to be only 0·01677. The semi axis major, or mean distance, being 1·0000, the greatest and least distances of the earth from the sun will be—

$$\text{B S} = 1{\cdot}0000 + 0{\cdot}01677 = 1{\cdot}01677$$
$$\text{A S} = 1{\cdot}0000 - 0{\cdot}01677 = 0{\cdot}98323.$$

The difference between these extreme distances is, therefore, only 0·03354. So that the difference between the greatest and least distances does not amount to so much as four hundredths of the mean distance.

149. **Perihelion and aphelion of the earth.**—The positions A and B, where the earth is nearest to, and most distant from, the sun are called PERIHELION and APHELION.

The positions of these points are ascertained by observing the places of the sun when its apparent diameter is greatest and least.

It is evident from what has been stated that the earth is in aphelion on the 1st of July, and in perihelion on the 1st of January.

Contrary to what might be expected, therefore, the earth is more distant from the sun in summer than in winter.

150. **Variations of temperature through the year.** — The succession of spring, summer, autumn, and winter, and the variations of temperature of the seasons — so far as these variations depend on the position of the sun — will now require to be explained.

The influence of the sun in heating a portion of the earth's surface, will depend partly on its altitude above the horizon. The greater that altitude is, the more perpendicularly the rays will fall, and the greater will be their calorific effect.

The calorific effect of the sun's rays on a surface more oblique to their direction than another will then be proportionably less.

If the sun be in the zenith, its rays will strike the surface perpendicularly, and the heating effect will therefore be greater than when the sun is in any other position.

The greater the altitude to which the sun rises, the less obliquely will be the direction in which its rays will strike the surface at noon, and the more effective will be their heating power. So far, then, as the heating power depends on the altitude of the sun, it will be increased with every increase of its meridian altitude.

Hence it is that the heat of summer increases as we approach the equator. The lower the latitude is, the greater will be the height to which the sun will rise. The meridian altitude of the sun at the summer solstice being everywhere outside the tropics forty-six degrees and fifty-six minutes more than at the winter solstice, the heating effect will be proportionately greater.

But this is not the only cause which produces the greatly superior heat of summer as compared with winter, especially in the higher latitudes. The heating effect of the sun depends not alone on its altitude at midday; it also depends on the length of time which it is above the horizon and below it. While the sun is above the horizon, it is continually imparting heat to the air and to the surface of the earth; and while it is below the horizon, the heat is continually being dissipated. The longer, therefore, — other things being the same, — the sun is above the horizon, and the shorter time it is below it, the greater will be the amount of heat imparted to the earth every twenty-four hours. Let us suppose that between sunrise and sunset, the sun, by its calorific effect, imparts a certain amount of heat to the atmosphere and the surface of the earth, and that from sunset to sunrise a certain amount of this heat is lost: the result of the action of the sun will be found by deducting the latter from the former.

Thus, then, it appears that the influence of the sun upon the seasons depends as much upon the length of the days and nights as upon its altitude; but it so happens that one of these circumstances depends upon the other. The greater the sun's meridional altitude is, the longer will be the days, and the shorter the nights; and the

less it is, the longer will be the nights, and the shorter the days. Thus both circumstances always conspire in producing the increased temperature of summer, and the diminished temperature of winter.

151. **Why the longest day is not also the hottest.—The dog-days.**—A difficulty is sometimes felt when the operation of these causes is considered, in understanding how it happens that, notwithstanding what has been stated, the 21st of June—when the sun rises the highest, when the days are longest and the nights shortest—is not the hottest day, but that, on the contrary, the dog-days, as they are called, which comprise the hottest weather of the year, occur in July and August; and in the same manner, the 21st of December—when the height to which the sun rises is least, the days shortest, aud the nights longest—is not usually the coldest day, but that, on the other hand, the most inclement weather occurs at a later period.

To explain this, so far as it depends on the position of the sun and the length of the days and nights, we are to consider the following circumstances:—

As midsummer approaches, the gradual increase of the temperature of the weather has been explained thus: The days being considerably longer than the nights, the quantity of heat imparted by the sun during the day is greater than the quantity lost during the night; and the entire result during the twenty-four hours gives an increase of heat. As this augmentation takes place after each successive day and night, the general temperature continues to increase. On the 21st of June, when the day is longest, and the night is shortest, and the sun rises highest, this augmentation reaches its maximum; but the temperature of the weather does not therefore cease to increase. After the 21st of June, there continues to be still a daily augmentation of heat, for the sun still continues to impart more heat during the day than is lost during the night. The temperature of the weather will therefore only cease to increase when by the diminished length of the day, the increased length of the night, and the diminished meridional altitude of the sun, the heat imparted during the day is just balanced by the heat lost during the night. There will be, then, no further increase of temperature, and the heat of the weather will have attained its maximum.

But it might occur to a superficial observer, that this reasoning would lead to the conclusion that the weather would continue to increase in its temperature, until the length of the days would become equal to the length of the nights; and such would be the case, if the loss of heat per hour during the night were equal to the gain of heat per hour during the day. But such is not the case; the loss is more rapid than the gain, and the consequence is

that the hottest day usually comes within the month of July, but always long before the day of the autumnal equinox.

The same reasoning will explain why the coldest weather does not usually occur on the 21st of December, when the day is shortest and the night longest, and when the sun attains the lowest meridional altitude. The decrease of the temperature of the weather depends upon the loss of heat during the night being greater than the gain during the day; and until, by the increased length of the day, and the diminished length of the night, these effects are balanced, the coldest weather will not be attained.

These observations must be understood as applying only so far as the temperature of the weather is affected by the sun, and by the length of the days and nights. There are a variety of other local and geographical causes which interfere with these effects, and vary them at different times and places.

On referring to the annual motion of the earth round the sun, it appears that the position of the sun within the elliptic orbit of the earth is such that the earth is nearest to the sun about the 1st of January, and most distant from it about the 1st of July. As the calorific power of the sun's rays increases as the distance from the earth diminishes, in even a higher proportion than the change of distances, it might be expected that the effect of the sun in heating the earth on the 1st of January would be considerably greater than on the 1st of July. If this were admitted, it would follow that the annual motion of the earth in its elliptic orbit would have a tendency to diminish the cold of the winter in the northern hemisphere, and mitigate the heat of summer, so as to a certain extent to equalise the seasons; and, on the contrary, in the southern hemisphere, where the 1st of January is in the middle of summer and the 1st of July the middle of winter, its effects would be to aggravate the cold in winter and the heat in summer. The investigations, however, which had been made in the physics of heat, have shown that that principle is governed by laws which counteract such effects. Like the operation of all other physical agencies, the sun's calorific power requires a definite time to produce a given effect, and the heat received by the earth at any part of its orbit will depend conjointly on its distance from the sun and the length of time it takes to traverse that portion of its orbit. In fact, it has been ascertained that the heating power depends as much on the rate at which the sun changes its longitude as upon the earth's distance from it. Now it happens that, in consequence of the laws of the planetary motions, discovered by Kepler, and explained by Newton, when the earth is most remote from the sun its velocity is least, and consequently the hourly changes of longitude of the sun will be proportionally less. Thus it appears that what the heating power loses by augmented

distance, it gains by diminished velocity; and again, when the earth is nearest to the sun, what it gains by diminished distance, it loses by increased speed. There is thus a complete compensation produced in the heating effect of the sun, by the diminished velocity of the earth which accompanies its increased distance.

This period of the year, during which the heat of the weather is usually most intense, was called the CANICULAR DAYS, or DOG DAYS. These days were generally reckoned as forty, commencing about the 3rd of July, and received their name from the fact, that in ancient times the bright star Sirius, in the constellation of Canis major, or the great dog, at that time rose a little before the sun, and it was to the sinister influence of this star that were ascribed the bad effects of the inclement heat, and especially the prevalence of madness among the canine race. Owing to a cause which will be explained hereafter (the precession of the equinoxes), this star no longer rises with the sun during the hot season.

CHAPTER VIII.

ATMOSPHERIC REFRACTION, AND PARALLAX.

152. **Apparent position of celestial objects affected by refraction.**—The ocean of air which surrounds, rests upon, and extends to a certain limited height above the surface of the solid and liquid matter composing the globe, decreases gradually in density in rising from the surface (H. 223); that when a ray of light passes from a rarer into a denser transparent medium, it is deflected towards the perpendicular to their common surface; and that the amount of such deflection increases with the difference of densities and the angle of incidence (O. 92). These properties, which air has in common with all transparent media, produce important effects on the apparent positions of celestial objects.

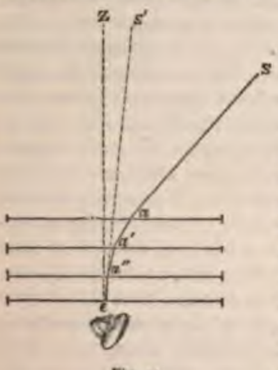

Fig. 44.

Let S *a*, *fig.* 44, be a ray of light coming from any distant ob-

ject, S, and falling on the surface of a series of layers of transparent matter, increasing in density downwards. The ray S a, pass-

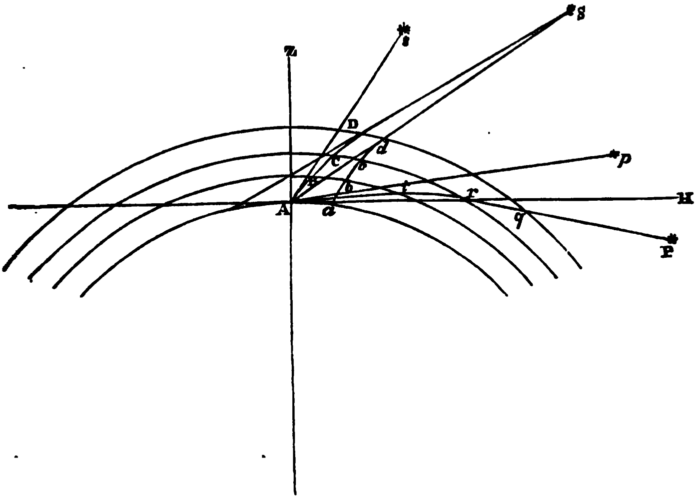

Fig. 45.

ing into the first layer, will be deflected in the direction a a' towards the perpendicular, and passing through the lowest layer, it will be still more deflected, and will enter the eye at e, in the direction a'' e; and since every object is seen in the direction from which the visual ray enters the eye, the object S will be seen in the direction e S$'$, instead of its true direction a S. The effect, therefore, is to make the object appear to be nearer to the zenithal direction than it really is.

And this is what actually occurs with respect to all celestial objects seen, as such objects always must be, through the atmosphere. The visual ray S D, *fig.* 45, passing through a succession of strata of air, gradually and continually increasing in density, its path will be a curve bending from D towards A, and convex towards the zenithal line A Z. The direction in which the object will be seen, being that in which the visual ray enters the eye, will be the tangent A s to the curve at A. The object will therefore be seen in the direction A s instead of D S.

It has been said that the deflection produced by refraction is increased with the increase of the angle of incidence. Now, in the present case, the angle of incidence is the angle under the true

direction of the object and the zenithal line, or, what is the same, the zenith distance of the object. The extent, therefore, to which any celestial object is disturbed from its true place by the refraction of the atmosphere, increases with its zenith distance. The refraction is, therefore, nothing in the zenith, and greatest in the horizon.

153. **Law of atmospheric refraction.**—The extent to which a celestial object is displaced by refraction, therefore, depends upon and increases with its distance from the zenith; and it can be shown to be a consequence of the general principles of optics, that when other things are the same, the actual quantity of this displacement (except at very low altitudes) varies in the proportion of the tangent of the zenith distance.

This law prevails with considerable exactitude, except at very low altitudes, where the refractions depart from it, and become uncertain.

154. **Quantity of refraction.**—When the latitude of the observatory is known, the actual quantity of refraction at a given altitude may be ascertained by observing the altitudes of a circumpolar star, when it passes the meridian above and below the pole. The sum of these altitudes would be exactly equal to twice the latitude (114) if the refraction did not exist, but since by its effects the star is seen at greater than its true altitudes, the sum of the altitudes will be greater than twice the latitude by the sum of the two refractions. This sum will therefore be known, and being divided between the two altitudes in the ratio of the tangents of the zenith distances the quantity of refraction due to each altitude will be known.

The pole star answers best for this observation, especially in these and higher latitudes, where it passes the meridian within the limits of the more regular influence of refraction; and the difference of its altitudes being only 3°, no considerable error can arise in apportioning the total refraction between the two altitudes.

155. **Tables of refraction.** — To determine with great exactitude the average quantity of refraction due to different altitudes, and the various physical conditions under which the actual refraction departs from such average, is an extremely difficult physical problem. These conditions are connected with phenomena subject to uncertain and imperfectly known laws. Thus, the quantity of refraction at a given altitude depends, not only on the density, but also on the temperature of the successive strata of air through which the visual ray has passed. Although as a general fact, it is apparent that the temperature of the air falls as we rise in the atmosphere, yet the exact law according to which it decreases is not fully ascertained. But even though it were, the refraction is also

influenced by other agencies, among which the hygrometric condition of the air holds an important place.

From these causes, some uncertainty necessarily attends astronomical observations of objects near the horizon, and some embarrassment arises in cases where the quantities to be detected by the observations are extremely minute. Nevertheless, it must be remembered that, since the total amount of refraction is never considerable, and in most cases it is extremely minute, and since, small as it is, it can be very nearly estimated and allowed for, and in some cases wholly effaced, no serious obstacle is offered by it to the general progress of astronomy.

Tables of refraction have been constructed and calculated, partly from observation and partly from theory, by which the observer may at once obtain the average quantity of refraction at each altitude; and rules are given by which this average refraction may be corrected according to the peculiar state of the barometer, thermometer, and other indicators of the physical state of the air.

156. **Average quantity at mean altitudes.**—While the refraction is nothing in the zenith, and somewhat greater than the apparent diameter of the sun or moon in the horizon, it does not amount to so much as 1′, or the thirtieth part of this diameter, at the mean altitude of 45°.

157. **Effect on rising and setting.**—Its mean quantity in the horizon is 33′, which being a little more than the mean apparent diameters of the sun and moon, it follows that these objects, at the moment of rising and setting, are visible above the horizon, the lower edge of their disks just touching it, when in reality they are below it, the upper edge of the disk just touching it.

The moments of rising of all objects are therefore accelerated, and those of setting retarded, by refraction. The sun and moon *appear* to rise *before* they have really risen, and to set *after* they have really set; and the same is true of all other objects.

158. **General effect of the barometer on refraction.**—Since the barometer rises with the increased weight and density of the air, its rise is attended by an augmentation, and its fall by a decrease, of refraction. It may be assumed that the refraction at any proposed altitude is increased or diminished by the 300th part of its mean quantity for every tenth of an inch by which the barometer exceeds or falls short of the height of 30 inches.

159. **Effect of thermometer.**—As the increase of temperature causes a decrease of density, the effect of refraction is diminished by the elevation of the thermometer, the state of the barometer being the same. It may be assumed, that the refraction at any proposed altitude is diminished or increased by the 420th part of its

mean amount for each degree by which Fahrenheit's thermometer exceeds or falls short of the mean temperature of 55°.

160. **Twilight caused by the reflection of the atmosphere.**—The sun continues to illuminate the clouds and the superior strata of the air after it has set, in the same manner as it shines on the summits of lofty mountain peaks long after it has descended from the view of the inhabitants of the adjacent plains. The air and clouds thus illuminated, reflect light to the surface below them; and thus, after sunset and before sunrise, produce that light, more or less feeble according to the depression of the sun, called TWILIGHT. Immediately after sunset the entire visible atmosphere, and all the clouds which float in it, are flooded with sunlight, and produce, by reflection, an illumination little less intense than before the sun had disappeared. According as the sun sinks lower and lower, less and less of the visible atmosphere receives his light, and less and less of it is transmitted by reflection to the surface, until at length, and by slow degrees, all reflection ceases and night begins.

The same series of phenomena are developed in an opposite order before sunrise in the morning, commencing with the first feeble light of dawn, and ending with the full blaze of day, when the disk of the sun becomes visible.

161. **Oval form of disks of sun and moon explained.**—One of the most curious effects of atmospheric refraction is the oval form of the disks of the sun and moon, when near the horizon. This arises from the unequal refraction of the upper and lower limbs. The latter being nearer the horizon is more affected by refraction, and therefore raised in a greater degree than the upper limb, the effect of which is to bring the two limbs apparently closer together, by the difference between the two refractions. The form of the disk is therefore affected as if it were pressed between two forces, one acting above, and the other below, tending to compress its vertical diameter, and to give it the form of an ellipse, the lesser axis of which is vertical, and the greater horizontal.

162. PARALLAX.—Since the apparent place of a distant object depends on the direction of the visual line drawn from the observer to such object, and since while the object remains stationary the direction of this visual line is changed with every change of position of the observer, such change of position produces necessarily a displacement in the apparent position of the object.

This apparent displacement of any object seen at a distance, due to the change of position of the observer, is called PARALLAX.

It follows that a distant object seen by two observers at different places on the earth is seen in different directions, so that its apparent place in the firmament will be different. It would therefore

follow, that the aspect of the heavens would vary with every change of position of the observer on the earth, just as the relative position of objects on land which are stationary changes when viewed from the deck of a vessel which sails or steams along the coast. But it so happens, that even the greatest difference of position which can exist between observers on the earth's surface is so small compared even with the nearest bodies to the earth, that the apparent displacement, or PARALLAX, thus produced is very small; while for the most numerous of celestial objects, the stars, it is absolutely inappreciable by the most refined means of observation and measurement.

Small as it is, however, so far as relates to the nearer bodies of the universe, it is capable of definite measurement, and its amount for each of them supplies one of the data by which their distances are calculated.

163. **Apparent and true place of an object. — Diurnal parallax.** — When an object is within such a limit of distance as would cause a sensible displacement to be produced when it is viewed from different parts of the earth's surface, it is convenient, in registering its apparent position at any given time, to adopt some fixed station from which it is supposed to be observed. The station selected by astronomers for this purpose is the centre of the earth. The direction in which an object would be seen if viewed from the centre of the earth is called its TRUE PLACE. The direction in which it is seen from any place of observation on the surface is called its APPARENT PLACE, and the apparent displacement which would be produced by the transfer of the observer from the centre to the surface or *vice versâ*, or, what is the same, the difference between the true and apparent places, is called the DIURNAL PARALLAX.

In *fig.* 46, let C represent the centre of the earth, P a place of observation on its surface, O an object seen in the zenith of P, O′ the same object seen at the zenith distance O P O′, and O″ the same object seen in the horizon.

It is evident that O will appear in the same direction, whether it be viewed from P or C. Hence it follows that in the zenith there is no diurnal parallax, and that there the apparent place of an object is its true place.

But if the object be at O′, then the apparent direction is P O′, while the true direction is C O′, and the apparent place of the object will be a', while its true place will be t'; and the diurnal parallax corresponding to the zenith distance O P O′ will be t' a', or the angle t' O′ a', which is equal to P O′ C.

As the object is more remote from the zenith the parallax is augmented, because the semidiameter C P of the earth, which passes

through the place of observation, is more and more nearly at right angles to the directions C O′ and P O′.

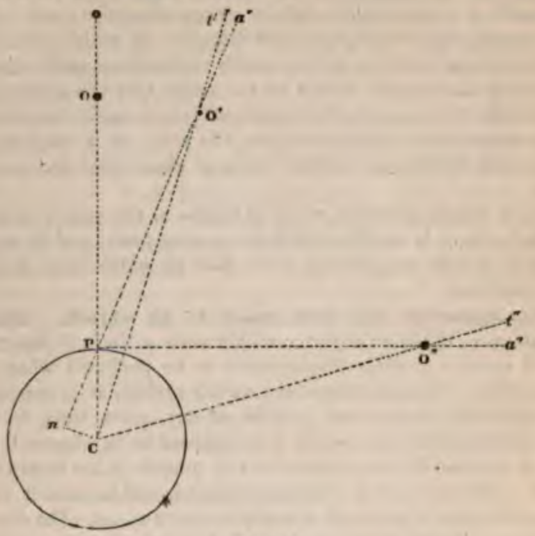

Fig. 46.

164. **Horizontal parallax.**— When the object is in the horizon, as at O″, the diurnal parallax becomes greatest, and is called the HORIZONTAL PARALLAX. It is the angle P O″ C which the semi-diameter of the earth subtends at the object.

165. **Annual parallax.**—If the earth be admitted to move annually around the sun, as a stationary centre, all observers placed on its surface, seeing distant objects from points of view so extremely distant one from the other as are the opposite extremities of its orbit, must necessarily, as might be supposed, see these objects in very different directions.

To comprehend the effect which might be expected to be produced upon the apparent place of a distant object by such a motion, let E E′ E″ E‴, *fig.* 47, represent the earth's annual course around the sun as seen in perspective, and let O be any distant object visible from the earth. The extremity E of the line E O which is the visual direction of the object, being carried with the earth round the circle E E′ E″ E‴, will annually describe a cone of which the base is the path of the earth, and the vertex is the place of the object O. While the earth moves round the circle E E″, the line of visual direction

would therefore have a corresponding motion, and the apparent place of the object would be successively changed with the change of direction of this line. If the object be imagined to be projected by the eye upon the firmament, it would trace upon it a path *o o′ o″ o‴*, which would be circular or elliptical, according to the direction of the object. When the earth is at E, the object would be seen at *o*; and when the earth is at E″, it would be seen at *o″*. The extent of this apparent displacement of the object would be measured by the angle E O E″, which the diameter E E″ of the earth's path or orbit would subtend at the object O.

It has been stated that, in general, the apparent displacement of a distant visible object produced by any change in the station from which it is viewed is called PARALLAX. That which is produced by the change of position due to the diurnal motion of the earth being called DIURNAL PARALLAX, the corresponding displacement due to the annual motion of the earth is called the ANNUAL PARALLAX.

The greatest amount, therefore, of the annual parallax for any proposed object is the angle which the semidiameter of the earth's orbit subtends at such object, as the greatest amount of the diurnal parallax is the angle which the semidiameter of the earth itself subtends at the object.

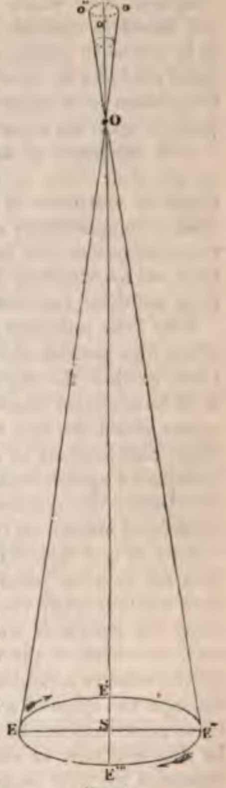

Fig. 47.

166. **Its effects upon the bodies of the solar system apparent.**—The effects of annual parallax are observable, and indeed are of considerable amount, in the case of all the bodies composing the solar system. The apparent annual motion of the sun is altogether due to parallax. The apparent motions of the planets and other bodies composing the solar system are the effects of parallax, combined with the real motions of these various bodies.

167. **General absence of parallax explained by great distance.**—With a few exceptions, no traces of the effects of annual parallax have been discovered among the innumerable fixed stars by which the solar system is surrounded, and since, nevertheless, the annual motion of the earth in its orbit rests upon a body of evi-

dence and is supported by arguments which must be regarded as conclusive, the absence of parallax can only be ascribed to the fact that the stars generally are placed at distances from the solar system compared with which the orbit of the earth shrinks into a point, and therefore that the motion of an observer round this orbit, vast as it may seem compared with all our familiar standards of magnitude, produces no more apparent displacement of a fixed star than the motion of an animalcule round a grain of mustard seed would produce upon the apparent direction of the moon or sun.

168. **Absence of sensible parallax of fixed stars.** — When, on any clear night, we contemplate the firmament, and behold the countless multitude of objects that sparkle upon it, remembering what a comparatively small number are comprised among those of the solar system, and even of these how few are visible at any one time, we are naturally impelled to the inquiry, Where in the universe are these vast numbers of objects placed?

Very little reflection and reasoning, applied to the consideration of our own position and to the appearance of the heavens, will convince us that the objects that chiefly appear on the firmament, must be at almost immeasurable distances. The earth in its annual course round the sun moves in a circle, the diameter of which is about 200 millions of miles. We, who observe the heavens, are transported upon it round that vast circle. The station from which we observe the universe at one period of the year is, then, 200 millions of miles from the station from which we view it at another.

Now it is a fact, within the familiar experience of every one, that the relative position of objects will depend upon the point from which they are viewed. If we stand upon the bank of a river, along the margin of which a multitude of ships are stationed, and view the masts of the vessels, they will have among each other a certain relative arrangement. If we change our position, however, through the space of a few hundred yards, the relative position of these masts will not be the same as before. Two which before lay in line will now be seen separate; and two which before were separated are now brought into line. Two, one of which was to the right of the other, are now reversed; that which was to the right, is at the left, and *vice versâ;* nor are these changes produced by any change of position of the ships themselves, for they are moored in stationary positions. The changes of appearance are the result of *our own change of position;* and the greater that change of position is, the greater will be the relative change of these appearances. Let us suppose, however, that we are moved to a much greater distance from the shipping; any change in our position will produce much less effect upon the relative position of the masts; perhaps it will require a very considerable change to produce a per-

ceivable effect upon them. Therefore, in proportion as our distance from the masts is increased, so in proportion will it require a greater change in our own position to produce the same apparent change in their position.

Thus it is with all visible objects. When a multitude of stationary objects are viewed at a distance, their relative position will depend upon the position of the observer; and if the station of the observer be changed, a change in the relative position of the objects must be expected; and if no perceptible change is produced, it must be inferred that the distance of the objects is incomparably greater than the change of position of the observer.

Let us now apply these reflections to the case of the earth and the stars. The stars are analogous to the masts of the ships, and the earth is the station on which the observer is placed. It might have been expected that the magnitude of the globe, being eight thousand miles in diameter, would produce a change of position of the observer sufficient to cause a change in the relative position of the stars, but we find that such is not the case. The stars, viewed from opposite sides of the globe, present exactly the same appearance; we must, therefore, infer that the diameter of the earth is absolutely nothing compared to their distance.

But the astronomer has still a much larger modulus to fall back upon. He reflects, as has been already observed, that he is enabled to view the stars from two stations separated from each other, not by 8000 miles, the diameter of the earth, but by 200 millions of miles, that of the earth's orbit. He, therefore, views the heavens on the 1st of January, and views them again on the 1st of July, the earth having in the meanwhile passed to the opposite side of its orbit, yet he finds, to his amazement, that the aspect is the same. He thinks that this cannot be—that so great a change of position in himself cannot fail to make some change in the apparent position of the stars;—that, although their general aspect is the same, yet when submitted to exact examination a change must assuredly be detected. He accordingly resorts to the use of instruments of observation capable of measuring the relative positions of the stars with the last conceivable precision, and he is more than ever confounded by the fact that still no discoverable change of position is found.

For a long period of time this result seemed inexplicable, and accordingly it formed the greatest difficulty with astronomers, in admitting the annual motion of the earth. The alternative offered was this; it was necessary, either to fall back upon the Ptolemaic system, in which the earth was stationary, or to suppose that the immense change of position of the earth in the course of half a year, could produce no discoverable change of appearance in the

stars; a fact which involves the inference that the diameter of the earth's orbit must be a mere point compared with the distance of the nearest stars. Such an idea appeared so inadmissible that for a long period of time many preferred to embrace the Ptolemaic hypothesis, beset as it was with difficulties and contradictions.

Improved means of instrumental observation and micrometrical measurement, united with the zeal and skill of observers, have at length surmounted these difficulties; and the parallax, small indeed but still capable of measurement, of several stars has been ascertained.

169. **Methods of ascertaining the parallax of fixed stars.** —It will easily be imagined that astronomers have diligently directed their observations to the discovery of some change of apparent position, however small, produced upon the stars by the earth's motion. As the stars most likely to be affected by the motion of the earth are those which are nearest to the system, and therefore probably which are brightest and largest, it has been to such chiefly that this kind of observation has been directed; and since it was certain that, if any observable effect be produced by the earth's motion at all, it must be extremely small, the nicest and most delicate means of observation were those alone from which the discovery could be expected.

One of the earlier expedients adopted for the solution of this problem was the erection of a telescope, of great length and power, in a position permanently fixed, attached, for example, to the side of a pier of solid masonry erected upon a foundation of rock. This instrument was screwed into such a position that particular stars, as they crossed the meridian, would necessarily pass within its field of view. Micrometric wires were, in the usual manner, placed in its eye-piece, so that the exact point at which the stars passed the meridian each night, could be observed and recorded with the greatest precision. The instrument being thus fixed and immovable, the transits of the stars were noted each night, and their exact places when they passed the meridian recorded. This kind of observation was carried on through the year; and if the earth's change of position, by reason of its annual motion, should produce any effect upon the apparent position of the stars, it was anticipated that such effect would be discovered by these means. After, however, making all allowance for the usual causes which affect the apparent position of the stars, no change of position was discovered which could be assigned to the earth's motion.

170. **Professor Henderson's discovery of the parallax of α Centauri.**—Notwithstanding the numerous difficulties which beset the solution of this problem, by means of observations made with the ordinary instruments, Professor Henderson, during his resi-

dence as astronomer at the Royal Observatory at the Cape of Good Hope, succeeded in making a series of observations upon the star designated α in the constellation of the Centaur, which, being afterwards submitted by him to the proper reductions, gave a parallax of about 1″. Subsequent observations made by his successor, Mr. Maclear, at the same observatory, partly with the same instrument, and partly with an improved and more efficient one of the same class, have fully confirmed this result, giving 0·9187, or $\frac{10}{11}$ths of a second as the parallax.

It is worthy of remark, that this conclusion of Messrs. Henderson and Maclear is confirmed in a remarkable manner, by the fact that like observations and computations applied to other stars in the vicinity of α Centauri, and therefore subject to like annual causes of apparent displacement, such as the mean annual variation of temperature, gave no similar result, showing thus that the displacement found in the case of α Centauri could only be ascribed to parallax.

Since the limits of error of this species of observation affecting the final result cannot exceed the tenth of a second, it may then be assumed as proved, that the parallax of α Centauri is about 1″, and consequently that its distance from the solar system is such that light must take more than three years to move over it.

171. **Parallax of a few stars ascertained.**—Notwithstanding the great number of stars to which instruments of observation of unlooked-for perfection, in the hands of the most able and zealous observers, have been directed, the results of such labours have hitherto been rather negative than positive. The means of observation have been so perfect, and their application so extensive, that it may be considered as proved by the absence of all measurable displacement consequent upon the orbital motion of the earth that, a very few individual stars excepted, the vast multitude of bodies which compose the universe and which are nightly seen glittering in the firmament, are at distances from the solar system greater than that which would produce an apparent displacement amounting to the tenth of a second. This limit of distances is, therefore, ten parallactic units, or about two million times the space between the earth and sun.

The parallax of the following stars has been determined within some degree of probability from the observations of MM. Henderson, Bessel, Krüger, Struve, and C. A. F. Peters. The names and amount of parallax of each star are α Centauri, 0″·976; 61 Cygni, 0″·348; Lalande 21258, 0″·260; Oeltzen-Argelander 17,415–6, 0″·247; Groombridge 1830, 0″·226; α Lyræ, 0″·155; Sirius, 0″·150; ι Ursæ Majoris, 0″·133; Arcturus, 0″·127; Polaris, 0″·067; and Capella, 0″·046.

The parallax of the first nine of these stars may be considered as having been ascertained with tolerable certainty and precision. The very small amount of that of the last two is such as to render it more doubtful. What is certain, however, in relation to these is, that the actual amount of their parallax is less than the tenth of a second.

CHAPTER IX.

PRECESSION AND NUTATION.

172. **Effects which would be produced if a satellite were attached to the surface of the earth at the equator.**— If the earth were attended by a second satellite, revolving close to its surface and in the plane of its equator, the periodic time of the satellite would be considerably less than that of the moon, in a ratio which is easily ascertained.

But such a satellite would be subject to the disturbing action of the sun, which would produce in its orbit inequalities similar in kind to, but different in magnitude from, those produced by the sun's disturbing force on the moon's orbit. Its nodes, that is, the equinoxial points (inasmuch as its orbit is by the supposition the plane of the equator), would receive a slow regressive motion; and its inclination, that is, the obliquity of the ecliptic, would be subject to a variation whose period would depend on that of the successive returns of the sun to the same equinoxial point.

This satellite would also be subject to the disturbing action of the moon, which would affect it in a manner nearly similar; since, in that case also, the disturbing body would be exterior to the disturbed. It would impart to the line of nodes of the supposed satellite, that is, to the intersection of the plane of its orbit with the plane of the earth's equator, a retrograde motion upon the former plane; and since that plane is inclined at a very small angle to the plane of the ecliptic, this would produce a like retrograde motion of the equinoxial points upon the ecliptic.

A variation of the inclination of the plane of the equator to that of the moon's orbit, and, therefore, to the plane of the ecliptic, would also be produced, the period of which would depend on the moon's motion.

But the moon's orbit would also be disturbed by the attraction of the supposed satellite. A regressive motion would be imparted to the line in which the plane of its orbit intersects that of the equator,

and a periodical variation of inclination would likewise be produced, depending on the period of the supposed satellite.

Let us now imagine that the supposed satellite, instead of revolving in a short period, moves with a much slower motion, and revolves in 23 hours and 56 minutes, the time of the earth's rotation. The inequalities which it suffers and which it produces, will then be changed only in their magnitudes and periods, but will retain the same general character. But the supposed satellite now having the same motion precisely as the surface of the earth close to which it is placed, may be imagined to adhere to that surface, so as to form, in fact, a part of the earth, without in any way deranging the conclusions which have been deduced above.

173. **Like effects would be produced by any number of such satellites, or what would be equivalent, by the spheroidal form.**—But the same observations would be equally applicable to any number of satellites similarly placed and similarly moving, which might, therefore, be imagined to be successively attached to the surface of the globe at and near the equator, until such a protuberance would be formed upon it, as would in effect convert it into the form of an oblate spheroid, such as the form of the earth is known to be.

It is, however, to be further considered, that the effects of the disturbing forces which thus act upon this protuberant matter, are necessarily modified by the inertia of the spherical mass within it, to which it is imagined to be attached. The protuberant mass which alone is acted on by the disturbing forces, cannot obey any action of these forces, without dragging with it this vast spherical mass to which it is united. The motions and changes of motion, therefore, which it receives, will be rendered slower in proportion to the mass with which such motions must be shared.

These observations are obviously applicable equally to any of the other planets, which being attended by satellites, have the spheroidal form.

174. **Precession of the equinoxes.**—Since, therefore, we may consider the spheroidal protuberance round the terrestrial equator as a satellite attached to the earth, it will follow that the general effect of the sun's disturbing force acting upon it, will be to impart to its nodes, that is, to the equinoxial points, a retrograde motion, which will be much slower than that which they would receive from the same cause, if this protuberant matter were not compelled to carry with it the mass of the earth contained within it.

The moon exercises a like disturbing force which produces a like regression of the nodes of the equator on the moon's orbit; and that orbit being inclined at a small angle to the ecliptic, this is attended with a like regression of the equinoxial points.

The mean annual regression of the equinoxial points upon the plane of the ecliptic arising from these causes, is $50''\cdot 1$.

175. **The sun returns to the equinoxial point before completing its revolution.** — Since the equinoxial points thus move backwards on the ecliptic, it follows that the sun, after it has in its annual course passed round the ecliptic, will arrive at either equinoxial point before it has made a complete revolution. The equinoxial point being $50''\cdot 1$ behind the position it had when the sun started from it, the sun will return to it after having moved through $50''\cdot 1$ less than a complete revolution. But since the mean hourly apparent motion of the sun is $147''\cdot 8$, it follows that the centre of the sun will return to the equinoxial point, $20^m\ 20^s\cdot 3$ before completing its revolution.

176. **Equinoxial and sidereal year.** — Hence is explained the fact, that while the sidereal year, or actual revolution of the earth round the sun, is $365^d\ 6^h\ 9^m\ 10^s\cdot 38$, the equinoxial revolution, or the time between two successive equinoxes of the same name, is $365^d\ 5^h\ 48^m\ 50^s\cdot 4$, the latter being less than the former by $20^m\ 20^s$.

The successive returns of the sun to the same equinoxial point must, therefore, always *precede* its return to the same point of the ecliptic by $20^m\ 20^s$ of time, and by $50''\cdot 1$ of space.

177. **Period of the precession.** — To determine the period in which the equinoxial points moving backwards constantly at this mean rate would make a complete revolution of the ecliptic, it is only necessary to find how often $50''\cdot 1$ must be repeated to make up $360°$, or, what is the same, to divide the number of seconds in $360°$ by $50\cdot 1$, which gives 25,868 years.

178. **Its effect upon the longitudes of celestial objects.** — Although this motion, slow as it is, is easily detected from year to year by modern instruments, it was not until the sixteenth century that its precise rate was ascertained. Small as is its annual amount, its accumulation, continued from year to year for a long period of time, causes a great displacement of all the objects in the heavens, in relation to the equinoxial points from which longitudes and right ascensions are measured. In $71\cdot 6$ years, the equinoxes retrograde $1°$, and therefore, in that time, the longitudes of all celestial objects of fixed position, such as the stars, have their longitudes augmented $1°$. Since the formation of the earliest catalogues in which the positions of the fixed stars were registered, the retrogression of the equinoxial points has amounted to $30°$, so that the present longitudes of all the objects consigned to these catalogues, is $30°$ greater than those which are there assigned to them.

179. **Precession of equinoxes produces a rotation of the pole of the equator round that of the ecliptic.** — If two diameters of the celestial sphere be imagined to be drawn, one perpen-

dicular to the plane of the equator and the other to that of the ecliptic, the angle included between them will obviously be equal to the angle under the equator and ecliptic; and since the extremities of these diameters are the poles of the equator and ecliptic, it follows that the arc of the heavens included between these poles is equal to the obliquity of the ecliptic.

But since a plane passing through these diameters is at right angles both to the equator and ecliptic, the line of equinoxes or the intersection of the planes of the equator and ecliptic, will be at right angles to that plane. If, therefore, the equinoxial points revolve round the ecliptic in a retrograde direction, it follows that the plane passing through the diameters above mentioned, and through the poles of the two circles to which the line joining these points is at right angles, will revolve with a like motion, round that diameter of the sphere which is at right angles to the plane of the ecliptic, and which therefore terminates in its poles. But since the pole of the celestial equator is upon this circle at a distance from the pole of the ecliptic equal to the obliquity of the ecliptic, it follows that the pole of the equator will be carried round the pole of the ecliptic, in a lesser circle parallel to the plane of the ecliptic, with a retrograde motion exactly equal to that of the equinoxial points.

180. **Distance of pole of equator from pole of ecliptic varies with the obliquity.**—And since the distance of the pole of the equator from that of the ecliptic must always be exactly equal to the obliquity of the ecliptic, it follows that every change which may take place, from whatever cause, in the position of the plane of the equator, whether the change affect the angle at which it is inclined to the ecliptic, or the position of the equinoxial points, must be attended with a corresponding change, either in the apparent distance of the pole of the equator from that of the ecliptic, or in the rate or direction of the motion of the latter round the former.

181. **Pole star varies from age to age.**—As the pole of the equator is carried with this slow motion round the pole of the ecliptic, its position for all popular, and even for some scientific, purposes is usually indicated by the nearest conspicuous star, for it rarely happens that any such star is found to coincide with its exact place. Such star is the pole star, for the time being; and it is clear from this motion of the pole, that the pole star must necessarily change from age to age.

The present polar star is a star of the second magnitude in the constellation called the "Lesser Bear," and its present distance from the exact position of the pole is $1° 26'$.

The motion of the pole as above described, however, is such

that this distance is gradually diminishing, and will continue to diminish until it is reduced to about half a degree; after which it will increase, and after the lapse of a long period of time, the pole will depart from this star, and it will cease to bear the name, or serve the purposes, of a pole star.

182. **Former and future pole stars.**—If upon any star-map a circle be traced round the pole of the ecliptic at a distance from it of 23°·5, such circle will pass through all positions which the pole of the equator will have in time to come, or has had in time past; and it will then be easily seen which are the conspicuous stars in whose neighbourhood it will pass in after ages, and near which it has passed in past ages, and which will become in future, or have been in past times, the pole star of the age.

In 12,000 years from the present time, for example, it will be found that the pole will pass within a few degrees of the star of the first magnitude in the constellation of "Lyra," called *α Lyræ*.

In tracing back in the same manner the position of the pole among the stars, it is found that at an epoch 3970, or nearly 4000 years, before the present time, the pole was 55° 15′ behind its present position in longitude; and at this time the nearest bright star to it was the star γ, in the constellation of "Draco." The distance of this star, at that time, from the pole must have been 3° 44′ 25″.

183. **Remarkable circumstance connected with the pyramids.**—In the researches which have been made in Egypt, a somewhat remarkable circumstance has been discovered, having relation to this subject.

Of the nine pyramids which still remain standing at Gizeh, six have openings presented to the north, leading to straight passages which descend at an inclination varying from 26° to 27°, the axes of the passages being in all cases in the plane of the meridian of the pyramid. Two pyramids, still standing at Abousseir, have similar openings leading to passages having similar directions.

Now, if we imagine an observer stationed at the bottom of any of these passages, and looking out along its axis as he would look through the tube of a telescope, his view will be directed to a point upon the northern meridian of the place of the pyramid at an altitude of between 26° and 27°, corresponding with the slope of the passage. This is precisely the altitude at which the star γ Draconis must have passed the meridian below the pole, at the date of 3970 years before the present time, allowing for the difference of position of the pole according to the principle affecting the precession of the equinoxes explained above. Now, the date of the construction of the pyramids corresponds almost exactly with this epoch; and it cannot be doubted, that the peculiar direction given to these

passages must have had reference to the position of γ Draconis, the pole star of that age.

184. **Nutation.** — The regression, already explained, of the equinoxial points upon the ecliptic, must be understood as their mean change of place produced by the disturbing forces of the sun and moon upon the protuberant matter of the equator in long periods of time. But this regression is not produced at a uniform rate. The disturbing forces vary in their actions according to the general principles already explained, with the angles formed by lines drawn from the sun and moon to the centre of the earth with the plane of the equator. So far as relates to the sun, this variation in its effect goes through all its changes within a year. In the case of the moon, it will obviously vary from month to month and from year to year, with the change of position of the moon's nodes; and as these nodes have a regressive motion making a complete revolution in about nineteen years, the variation of the effect of the moon's disturbing force will pass through all its changes within that period. The regressive motion imparted to the equinoxial points, and also to the pole of the equator in moving round the pole of the ecliptic, as already described, by the sun and moon, is therefore subject to an alternate increase and decrease, whose period is a year for the sun, and nineteen years for the moon.

But these are not the only effects produced upon the position of the pole of the equator by the disturbing action of the moon and sun. According to the effects of the orthogonal component of the disturbing force, it will be easily understood that the protuberant matter of the equator being regarded as a satellite disturbed by the sun and moon, the inclination of the plane of the equator to the ecliptic will be subject to a variation proceeding from the disturbing force of the sun, whose period will be a year; and its inclination to the plane of the moon's orbit will be subject to a like variation whose period is about nineteen years. These changes of the inclination of the plane of the equator to that of the ecliptic and the moon's orbit will be attended with a corresponding motion of the pole of the equator to and from the pole of the ecliptic.

This alternate approach and recess of the pole of the equator to and from the pole of the ecliptic, combined with the alternate increase and decrease of its regressive motion, is called the NUTATION; that part of it due to the sun being called the *solar nutation*; and that due to the moon, the *lunar nutation*.

The solar nutation is an inequality of so small amount as altogether to escape observation, and therefore must be looked upon to have a merely theoretical existence.

It is otherwise, however, with the lunar nutation. By the alter-

nate increase and decrease of the regressive motion of the pole, combined with its alternate approach and recess to and from the pole of the ecliptic, the pole is moved in such a manner that, if it were affected only by the disturbing force of the moon, it would describe an ellipse such as A B C D, *fig.* 48; the major axis of which would be in the direction A E of the pole of the ecliptic, and would measure 18″·5, while the minor axis would be at right angles to this direction, and would measure 13″·74.

Fig. 48.

But while the pole of the equator describes this ellipse completing its revolution in nineteen years, it is carried by the common motion of precession, in a retrograde direction, as already described, at the rate of 50″·1 in each year, and will, therefore, in nineteen years be carried through 15′·5 in its motion round the pole of the equator. Now, by combining this motion with the elliptic motion already described, it will be easily seen that the pole of the equator would, in revolving round the pole of the ecliptic, alternately approaching to it and receding from it through 9″·25, describe an undulating line such as is represented in *fig* 49, where P represents the pole of the ecliptic.

185. **Equation of the equinoxes.**—Since the regression of the equinoxes does not take place at an uniform rate, but is subject to variations, alternately increasing and decreasing during every nineteen years, its true place will differ from its mean place. If we conceive an imaginary equinoxial point moving backward, with an uniform motion at the rate of 50″·1, the place of such point would be the mean place of the equinoxial point. The true place would vary from this, preceding it when the disturbing force augments the rate at which the equinoxial point moves, and falling behind it when it decreases that rate.

Fig. 49.

The distance between the true and imaginary equinoxial points is called the EQUATION OF THE EQUINOXES.

The mean place of the equinox for any proposed time is given by tables; and the equation of the equinoxes for the proposed time gives the quantity to be added to, or subtracted from, the mean place, to find the true place.

186. **Proportion of the mean precession due to the disturbing forces of the moon and sun.**—If the entire amount of the mean precession in a given time be expressed by 7, the part due to the moon will be 5, and that due to the sun will be 2.

187. **Like effects produced in the case of other planets.**—These disturbing effects produced upon the plane of the planet's equator, are not confined to the case of the earth. All the planets which have the spheroidal form, are subject to similar effects from the sun's attraction on their equatorial protuberance, the magnitude of these effects being, however, less as the distance from the sun is increased. In the case of the major planets, the sun's disturbing action on the planet's equator, proceeding from this cause, will be altogether insensible.

The disturbing forces of the satellites exerted upon the plane of the equator, in the cases of the major planets, however, must be considerable in magnitude, especially so far as relates to the inner satellites, and very complicated in its character, the precession and nutation of each of the satellites separately being combined in affecting the actual position of the pole of the planet.

Since, however, these phenomena are necessarily local, and manifested only to observers on the planet, they offer merely speculative interest to the terrestrial astronomer.

CHAPTER X.

THE MOON.

188. **The moon an object of popular interest.**—Although it be in mere magnitude, and physically considered, one of the most insignificant bodies of the solar system, yet for various reasons, the MOON has always been regarded by mankind with feelings of profound interest, and has been invested by the popular mind with various influences, affecting not only the physical condition of the globe, but also the phenomena of the organised world. It has been as much an object of popular superstition as of scientific observation. These circumstances, doubtless, are in some degree owing to

its striking appearance in the firmament, to the various changes of form to which it is subject, and above all to its proximity to the earth, and the close alliance between it and our planet.

189. **Its distance.**—The distance of the moon from the earth is assumed to be about thirty times the earth's diameter, or in round numbers 238,800 miles.

190. **Linear value of 1″ on it.**—The linear value which corresponds to the visual angle of one second of space on the surface of the moon is 1·158 mile.* Any space, therefore, upon the moon, measured by its visual angle, can be reduced to its actual linear value, provided its direction be at right angles to the visual ray, which it will be if it be at the centre of the lunar disk. If it be between the centre and the edges it will be foreshortened by the obliquity of the moon's surface to the line of vision, and, consequently, the linear value thus computed will be the real linear value diminished by projection, which, however, can be easily allowed for, so that the true linear value can be obtained for every part of the lunar disk.

191. **Its apparent and real diameter.**—The apparent diameter of the moon is subject to a slight variation, owing to a corresponding variation due to the small ellipticity of its orbit. Its mean value is found to be 31′ 9″·58, or, from the most exact methods, 2164 miles.

Since the superficial magnitude of spheres is as the squares, and their volume or solid bulk as the cubes, of their diameters, it follows, that the superficial extent of the moon is about the fourteenth part of the surface, and its volume about the forty-ninth part of the bulk, of our globe.

192. **Apparent and real motion.**—The moon, like the sun, appears to move upon the celestial sphere in a direction contrary to that of the diurnal motion. Its apparent path is a great circle of the sphere, inclined to the ecliptic at an angle of about 5° 8′ 48″. It completes its revolution of the heavens in $27^d\ 7^h\ 43^m$.

This apparent motion is explained by a real motion of the moon round the earth at the mean distance above mentioned, and in the time in which the apparent revolution is completed.

193. **Hourly motion, apparent and real.**—Since the time taken by the moon to make a complete revolution, or 360° of the heavens, is $27^d\ 7^h\ 43^m$, or $655^h{\cdot}72$, it follows, that her mean apparent motion per day is 13° 10′ 35″, and per hour is 32′ 56″, which is a little more than her mean apparent diameter. The rate of the moon's apparent motion on the firmament may therefore be remembered by the fact, that she moves over the length of her own apparent diameter in an hour.

* For the method of determining the linear value of an arc of 1°, 1′, or 1″ at a distant object, *see* Chapter XXIII.

Since the linear value of 1″ at the moon's distance is 1·158 mile, the linear value of 1′ is 69 miles, and, consequently, the real motion of the moon per hour in her orbit, is 2189 miles. Her orbital motion is therefore at the rate of 36½ miles per minute.

194. **Orbit elliptical.**—Although in its general form and character the path of the moon round the earth is, like the orbits of the planets and satellites, circular, yet when submitted to accurate observation, we find that it is strictly an ellipse or oval, the centre of the earth occupying one of its *foci*. This fact can be ascertained by immediate observation upon the apparent magnitude of the moon. It will be easily comprehended that any change which the apparent magnitude, as seen from the earth, undergoes, must arise from corresponding changes in the moon's distance from us. Thus, if at one time the disk of the moon appears larger than at another time, as it cannot be supposed that the actual size of the moon itself could be changed, we can only ascribe the increase of the apparent magnitude to the diminution of its distance. Now we find by observation that such apparent changes are actually observed in its monthly course around the earth. The moon is subject to a small though perceptible variation of apparent size. We find that it diminishes until it reaches a minimum, and then gradually increases until it reaches a maximum.

When the apparent magnitude is least, it is at its greatest distance, and when greatest, at its least distance. The positions in which these distances lie are directly opposite. Between these two positions the apparent size of the moon undergoes a regular and gradual change, increasing continually from its minimum to its maximum, and consequently between these positions its distance must gradually diminish from its maximum to its minimum. If we lay down on a chart or plan a delineation of the course or path thus determined, we shall find that it will represent an oval, which differs however very little from a circle; the place of the earth being nearer to one end of the oval than the other.

195. **Moon's apsides—apogee and perigee—progression of the apsides.**—The point of the moon's path in the heavens at which its magnitude appears the greatest, and when, therefore, it is nearest the earth, is called its PERIGEE; and the point where its apparent size is least, and where, therefore, its distance from the earth is greatest, is called its APOGEE. These two points are called the MOON'S APSIDES.

If the positions of these points in the heavens be observed accurately for a length of time, it will be found that they are subject to a regular change; that is to say, the place where the moon appears smallest will every month shift its position; and a corresponding

change will take place in the point where it appears largest. The movement of these points in the heavens is found to be in the same direction as the general movement of the planets; that is, from west to east, or progressive. This phenomenon is called the PROGRESSION OF THE MOON'S APSIDES.

The rate of this progression of the moon's apsides makes a complete revolution in a similar direction as the motion of the moon, in 3232·5753 mean solar days, or nearly nine years.

196. **Moon's nodes—ascending and descending node—their retrogression.**—If the position of the moon's centre in the heavens be observed from day to day, it will be found that its apparent path is a great circle, making an angle of about 5° with the ecliptic. This path consequently crosses the ecliptic at two points in opposite quarters of the heavens. These points are called the MOON'S NODES. Their positions are ascertained by observing from time to time the distance of the moon's centre from the ecliptic, which is the moon's latitude; by watching its gradual diminution, and finding the point at which it becomes nothing; the moon's centre is then in the ecliptic, and its position is the NODE. The node at which the moon passes from the south to the north of the ecliptic is called the ASCENDING NODE, and that at which it passes from the north to the south is called the DESCENDING NODE.

These points, like the apsides, are subject to a small change of position, but in a retrograde direction. They make a complete revolution of the ecliptic in a direction contrary to the motion of the sun in 18·6 years, being at the rate of 3′ 10″·6 per day.

197. **Rotation on its axis.**—While the moon moves round the earth thus in its monthly course, we find, by observations of its appearance, made even without the aid of telescopes, that the same hemisphere is always turned towards us. We recognise this fact by observing that the same marks are always seen in the same positions upon it. Now in order that a globe which revolves in a circle around a centre should turn continually the same hemisphere towards that centre, it is necessary that it should make one revolution upon its axis in the time it takes so to revolve. For let us suppose that the globe, in any one position, has the centre round which it revolves north of it, the hemisphere turned toward the centre is turned toward the north. After it makes a quarter of a revolution, the centre is to the east of it, and the hemisphere which was previously turned to the north must now be turned to the east. After it has made another quarter of a revolution the centre will be south of it, and it must be now turned to the south. In the same manner, after another quarter of a revolution, it must be turned to the west. As the same hemisphere is successively turned to all the points of the compass in one revolution, it

is evident that the globe itself must make a single revolution on its axis in that time.

It appears, then, that the rotation of the moon upon its axis, being equal to that of its revolution in its orbit, is $27^d\ 7^h\ 43^m$, or $655^h\ 43^m$. The intervals of light and darkness to the inhabitants of the moon, if there were any, would then be altogether different from those provided in the planets; there would be about $327^h\ 52^m$ of continued light alternately with $327^h\ 52^m$ of continued darkness; the analogy, then, which, as will hereafter appear, prevails among the planets with regard to days and nights, and which forms a main argument in favour of the conclusion that they are inhabited globes like the earth, does not hold good in the case of the moon.

198. **Inclination of axis of rotation.**—Although as a general proposition it be true that the same hemisphere of the moon is always turned toward the earth, yet there are small variations at the edge called librations, which it is necessary to notice. The axis of the moon is not exactly perpendicular to its orbit, being inclined to the ecliptic at the small angle of $1°\ 30'\ 10''\cdot 8$. By reason of this inclination, the northern and southern poles of the moon lean alternately in a slight degree to and from the earth.

199. **Libration in latitude.**—When the north pole leans towards the earth, we see a little more of that region, and a little less when it leans the contrary way. This variation in the northern and southern regions of the moon visible to us, is called the LIBRATION IN LATITUDE.

200. **Libration in longitude.**—In order that in a strict sense the same hemisphere should be continually turned toward the earth, the time of rotation upon its axis must not only be equal to the time of rotation in its orbit, which in fact it is, but its angular velocity on its axis in every part of its course, must be exactly equal to its angular velocity in its orbit. Now it happens that while its angular velocity on its axis is rigorously uniform throughout the month, its angular velocity in its orbit is subject to a slight variation; the consequence of this is that a little more of its eastern or western edge is seen at one time than at another. This is called the LIBRATION IN LONGITUDE.

201. **Diurnal libration.**—By the diurnal motion of the earth, we are carried with it round its axis; the stations from which we view the moon in the morning and evening, or rather when it rises and when it sets, are then different according to the latitude of the earth in which we are placed. By thus viewing it from different places, we see it under slightly different aspects. This is another cause of a variation, which we see in its eastern and western edges: this is called the DIURNAL LIBRATION.

202. **Phases of the moon.**—While the moon revolves round

the earth, its illuminated hemisphere is always presented to the sun; it therefore takes various positions in reference to the earth. In *fig.* 50, the effects of this are exhibited. Let E S represent the di-

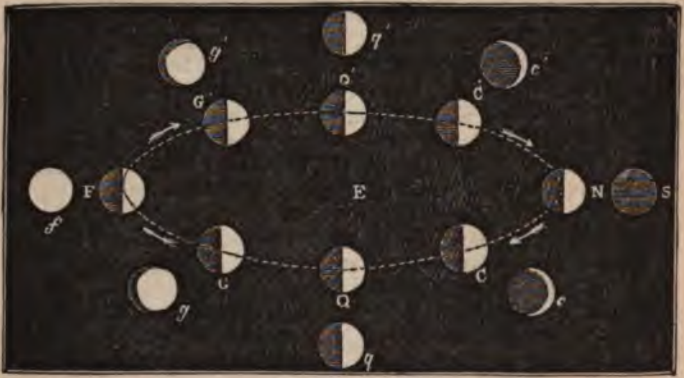

Fig 50.

rection of the sun, and E the earth: when the moon is at N, between the sun and the earth, its illuminated hemisphere being turned toward the sun, its dark hemisphere will be presented toward the earth; it will therefore be invisible. In this position the moon is said to be in CONJUNCTION.

When it moves to the position C, the enlightened hemisphere being still presented to the sun, a small portion of it only is turned to the earth, and it appears as a thin crescent, as represented at *c*.

When the moon takes the position of Q, at right angles to the sun it is said to be in QUADRATURE; one half of the enlightened hemisphere only is then presented to the earth, and the moon appears halved as represented at *q*.

When it arrives at the position G, the greater part of the enlightened portion is turned to the earth, and it is gibbous, appearing as represented at *g*.

When the moon comes in OPPOSITION to the sun, as seen at F, the enlightened hemisphere is turned full toward the earth, and the moon will appear full as at *f*, unless it be obscured by the earth's shadow, which rarely happens. In the same manner it is shown that at G′ it is again gibbous; at Q′ it is halved, and at C′ it is a crescent.

When the moon is full, being in opposition to the sun, it will necessarily be in the meridian at midnight, and will rise nearly as

the sun sets, and set nearly as the sun rises; and thus, whenever the enlightened hemisphere is turned toward us, and when, therefore, it is the most capable of benefiting us, it is above the horizon all night; whereas, when it is in conjunction, as at N, and the dark hemisphere is turned toward us, it would then be of no use to us, and is accordingly above the horizon during the day. The position at Q is called the "first quarter," and at Q′ the "last quarter." The position at C is called the first octant; G the second octant; G′ the third octant; and C′ the fourth octant. At the first and fourth octants it is a crescent, and at the second and third octants it is gibbous.

203. **Synodic period or common month.**—The apparent motion of the moon in the heavens is much more rapid than that of the sun; for while the sun makes a complete circuit of the ecliptic in 365·25 days, and therefore moves over it at about 61′ per day, the moon moves at the rate of 13° 10′ 35″ (193) per day. As the sun and moon appear to move in the same direction in the firmament, both proceeding from west to east, the moon will, after conjunction, depart from the sun toward the east at the rate of about 12° 9′ per day. If then, the moon be in conjunction with the sun on any given day, it will be 12° 9′ east of it at the same time on the following day; 24° 18′ east of it after two days, and so on. If, then, the moon set with the sun on any evening, it will, at the moment of sunset on the following evening, be 12° 9′ east of the sun, and at sunset will appear as a thin crescent, at a considerable altitude; on the succeeding day it will be 24° 18′ east of the sun, and will be at a still greater altitude at sunset, and will be a broader crescent. After seven days, the moon will be removed nearly 90° from the sun; it will be at or near the meridian at sunset. It will remain in the heavens for about six hours after sunset, and will be seen in the west as the half-moon. Each successive evening increasing its distance from the sun, and also increasing its breadth, it will be visible in the meridian at a later hour, and will consequently be longer apparent in the firmament during the night—it will then be gibbous. After about fifteen days, it will be 180° removed from the sun, and will be full, and consequently will rise when the sun sets, and set when the sun rises—being visible the entire night. After the lapse of about twenty-two days, the distance of the moon from the sun being about 270°, it will not reach the meridian until nearly the hour of sunrise; it will then be visible during the last six hours of the night only. The moon will then be waning, and toward the close of the month will only be seen in the morning before sunrise, and will appear as a crescent.

If the earth and sun were both stationary while the moon revolves round the former, the period of the phases would be the same as the period of the moon. But from what has been explained, it will

be evident that while the moon makes its apparent revolution of the heavens in about 27·3 days, the sun advances through somewhat more than 27° of the heavens, *in the same direction.* Before the moon can reassume the same phase, it must have the same position relative to the sun, and must, therefore, overtake it. But since it moves at the rate of about 1° in two hours, it will take more than two days to move over 27°. Hence the SYNODIC PERIOD, or lunar month, or the interval between two successive conjunctions, is about two days longer than the sidereal period of our satellite.

The exact length of the synodic period is $29^d\ 12^h\ 44^m\ 2^s{\cdot}87$, or 29·53059 mean solar days.

204. **Mass and density.** — The result of the most recent solutions of this problem, by various methods and on different data, proves that the mass or quantity of matter composing the globe of the moon is a little more than the 80th part of the mass of the earth; or, more exactly, if the mass of the earth consist of a million of equal parts, the mass of the moon will be equal to 12,500 of these parts.

Since the volume or bulk of the moon is about the 50th part of that of the earth, while its mass or weight is little more than the 80th part of that of the earth, it follows that its mean density must be little more than half the density of the earth.

205. **No air upon the moon.** — In order to determine whether or not the globe of the moon is surrounded with any gaseous envelope like the atmosphere of the earth, it is necessary first to consider what appearances such an appendage would present, seen at the moon's distance, and whether any such appearances are discoverable.

According to ordinary and popular notions, it is difficult to separate the idea of an atmosphere from the existence of clouds; yet to produce clouds something more is necessary than air. The presence of water is indispensable, and if it be assumed that no water exist, then certainly the absence of clouds is no proof of the absence of an atmosphere. Be this as it may, however, it is certain that there are no clouds upon the moon, for if there were, we should immediately discover them, by the variable lights and shadows they would produce. If there be, then, an atmosphere upon the moon, it is one entirely unaccompanied by clouds.

One of the effects produced by a distant view of an atmosphere surrounding a globe, one hemisphere of which is illuminated by the sun, is, that the boundary, or line of separation between the hemisphere enlightened by the sun and the dark hemisphere, is not sudden and sharply defined, but is gradual — the light fading away by slow degrees into the darkness.

It is to this effect upon the globe of the earth that twilight

is owing, and such a gradual fading away of the sun's light is discoverable on some of the planets, upon which an atmosphere is observed.

Now, if such an effect of an atmosphere were produced upon the moon, it would be perceived by the naked eye, and still more distinctly with the telescope. When the moon appears as a crescent, its concave edge is the boundary which separates the enlightened from the dark hemisphere. When it is in the quarters, the diameter of the semicircle is also that boundary. In neither of these cases, however, do we ever discover the slightest indication of any such appearance as that which has just been described. There is no gradual fading away of the light into the darkness; on the contrary, the boundary, though serrated and irregular, is nevertheless perfectly well-defined and sudden.

All these circumstances conspire to prove that there does not exist upon the moon an atmosphere capable of reflecting light in any sensible degree.

The magnitude and motion of the moon and the relative positions of the stars are so accurately known, that nothing is more easy, certain, and precise, than the observations which may be made with the view of ascertaining whether any stars are ever seen which are sensibly behind the edge of the moon. Such observations have been made, and no such effect has ever been detected. This species of observation is susceptible of such extreme accuracy, that it is certain that if an atmosphere existed upon the moon a thousand times less dense than our own, its presence must be detected.

Bessel has calculated that if the difference between the apparent diameter of the moon, and the arc of the firmament moved over by the moon's centre during the occultation of a star, centrically occulted, were admitted to amount to so much as 2″, and allowing for the possible effect of mountains, by which the edge of the disk is serrated, taking these at the extreme height of 24,000 feet, the density of the lunar atmosphere, whose refraction would produce such an effect, would not exceed the 968th part of the density of the earth's atmosphere, supposing the two fluids to be similarly constituted. Nor would this conclusion be materially modified by any supposition of an atmosphere composed of gases different from the constituents of the earth's atmosphere.

The earth's atmosphere supports a column of 30 inches of mercury; an atmosphere 1000 times less dense would support a column of three-tenths of an inch only. We may therefore consider it as an established fact, that no atmosphere exists on the moon having a density even as great as that which remains under the receiver of the most perfect air-pump, after that in-

strument has withdrawn from it the air to the utmost extent of its power.

If further proofs of the nonexistence of a lunar atmosphere were required, Sir J. Herschel indicates several which are found in the phenomena of eclipses. In a solar eclipse the existence of an atmosphere having any sensible refraction, would enable us to trace the limb of the moon beyond the cusps externally to the sun's disk, by a *narrow but brilliant* line of light extending to some distance along its edge. No such phenomenon has, however, been seen.

If there were any appreciable quantity of vapour suspended over the moon's surface, *very* faint stars ought to disappear behind it before the moment of their occultation by the interposition of the moon's edge. Such, however, is not the case. When occulted at the enlightened edge of the lunar disk, the light of the moon overpowers them and renders them invisible, and even at the dark edge the glare in the sky, caused by the proximity of the enlightened part of the disk, renders the occultation of extremely minute stars incapable of observation.

206. **Moonlight not sensibly calorific.** — It has long been an object of inquiry whether the light of the moon has any heat, but the most delicate experiments and observations have failed to detect this property in it. The light of the moon was collected into the focus of a concave mirror of such magnitude as would have been sufficient, if exposed to the sun's light, to evaporate gold or platinum. The bulb of a differential thermometer, sensitive enough to show a change of temperature amounting to the 500th part of a degree, was placed in its focus so as to receive upon it the concentrated rays. Yet no sensible effect was produced. We must, therefore, conclude that the light of the moon does not possess the calorific property in any sensible degree. But if the rays of the moon be not warm, the vulgar impression that they are cold is equally erroneous. We have seen that they produce no effect either way on the thermometer.

207. **No liquids on the moon.**—The same physical tests which show the nonexistence of an atmosphere of air upon the moon are equally conclusive against an atmosphere of vapour. It might, therefore, be inferred that no liquids can exist on the moon's surface, since they would be subject to evaporation. Sir John Herschel, however, ingeniously suggests that the nonexistence of vapour is not conclusive against evaporation. One hemisphere of the moon being exposed continuously for 328 hours to the glare of sunshine of an intensity greater than a tropical noon, because of the absence of an atmosphere and clouds to mitigate it, while the other is for an equal interval exposed to a cold far more rigorous than

that which prevails on the summits of the loftiest mountains or in the polar region, the consequence would be the immediate evaporation of all liquids which might happen to exist on the one hemisphere, and the instantaneous condensation and congelation of the vapour on the other. The vapour would, in short, be no sooner formed on the enlightened hemisphere, than it would rush to the vacuum over the dark hemisphere, where it would be instantly condensed and congealed, an effect which Herschel aptly illustrates by the familiar experiment of the CRYOPHORUS. The consequence, as he observes, of this state of things would be absolute aridity below the vertical sun, constant accretion of hoar frost in the opposite region, and perhaps a narrow zone of running water at the borders of the enlightened hemisphere. He conjectures that this rapid alternation of evaporation and condensation may to some extent preserve an equilibrium of temperature, and mitigate the severity of both the diurnal and nocturnal conditions of the surface. He admits nevertheless that such a supposition could only be compatible with the tests of the absence of a transparent atmosphere even of vapour within extremely narrow limits; and it remains to be seen whether the general physical condition of the lunar surface as disclosed by the telescope be not more compatible with the supposition of the total absence of all liquid whatever.

It appears to have escaped the attention of those who assume the possibility of the existence of water in the liquid state on the moon, that in the absence of an atmosphere, the temperature must necessarily be, not only far below the point of congelation of water, but even that of most other known liquids. Even within the tropics, and under the line with a vertical sun, the height of the snow line does not exceed 16,000 feet; and nevertheless at that elevation, and still higher, there prevails an atmosphere capable of supporting a considerable column of mercury. At somewhat greater elevations, but still in an atmosphere of very sensible density, mercury is congealed. Analogy, therefore, justifies the inference that the total, or nearly total, absence of air upon the moon is altogether incompatible with the existence of water, or probably any other body in the liquid state, and necessarily infers a temperature altogether incompatible with the existence of organised beings in any respect analogous to those which inhabit the earth.

But another conclusive evidence of the nonexistence of liquids on the moon is found in the form of its surface, which exhibits none of those well understood appearances which result from the long continued action of water. The mountain formations with which the entire visible surface is covered are, as will presently appear, universally so abrupt, precipitous, and unchangeable, as to be utterly incompatible with the presence of liquids.

208. **Absence of air deprives solar light and heat of their utility.**—The absence of air also prevents the diffusion of the solar light. The general diffusion of the sun's light upon the earth is mainly due to the reflection and refraction of the atmosphere, and to the light reflected by the clouds; and that without such means of diffusion, the solar light would only illuminate those places into which its rays would directly penetrate. Every place not in full sunshine, or exposed to some illuminated surface, would be involved in the most pitchy darkness. The sky at noon-day would be intensely black, for the beautiful azure of our firmament in the day-time is due to the reflected colour of the air.

Thus it appears that the absence of air must deprive the sun's illuminating and heating agency of nearly all its utility. If no diffusion of light and no retention and accumulation of heat, such as an atmosphere supplies, prevail, it is impossible to conceive the existence and maintenance of an organised world having any analogy to the earth.

209. **As seen from the moon, appearance of the earth and the firmament.**—If the moon were inhabited, observers placed upon it would witness celestial phenomena of a singular description, differing in many respects from those presented to the inhabitants of our globe. The heavens would be perpetually serene and cloudless. The stars and planets would shine with extraordinary splendour during the long night of 328 hours. The inclination of her axis being only 5°, there would be no sensible changes of season. The year would consist of one unbroken monotony of equinox. The inhabitants of one hemisphere would never see the earth: while the inhabitants of the other would have it constantly in their firmament by day and by night, and always in the same position. To those who inhabit the central part of the hemisphere presented to us, the earth would appear stationary in the zenith, and would never leave it, never rising nor setting, nor in any degree changing its position in relation to the zenith, or horizon. To those who inhabit places intermediate between the central part of that hemisphere and those places which are at the edge of the moon's disk, the earth would appear at a fixed and invariable distance from the zenith, and also at a fixed and invariable azimuth, the distance from the zenith being everywhere equal to the distance of the observer from the middle point of the hemisphere presented to the earth. To an observer at any of the places which are at the edge of the lunar disk, the earth would appear perpetually in a fixed direction on the horizon.

The earth shone upon by the sun would appear as the moon does to us; but with a disk having an apparent diameter greater than that of the moon in the ratio of 79 to 21, and an apparent superficial

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magnitude about fourteen times greater, and it would consequently have a proportionately illuminating power.

Earth light at the moon would, therefore, be about fourteen times more intense than *moonlight* at the earth. The earth would go through the same phases and complete the series of them in the same period as that which regulates the succession of the lunar phases, but the corresponding phases would be separated by the interval of half a month. When the moon is *full* to the earth, the earth is *new* to the moon, and *vice versâ:* when the moon is a crescent, the earth is gibbous, and *vice versâ.*

The features of light and shade would not, as on the moon, be all permanent and invariable. So far as they would arise from the clouds floating in the terrestrial atmosphere, they would be variable. Nevertheless, their arrangement would have a certain relation to the equator, owing to the effect of the prevailing atmospheric currents parallel to the line.* This cause would produce streaks of light and shade, the general direction of which would be at right angles to the earth's axis, and the appearance of which would be in all respects similar to the BELTS which, as will appear hereafter, are observed upon some of the planets, and which are ascribed to a like physical cause.

Through the openings of the clouds the permanent geographical features of the surface of the earth would be apparent, and would probably exhibit a variety of tints according to the prevailing characters of the soil, as is observed to be the case with the planet Mars even at an immensely greater distance. The rotation of the earth upon its axis would be distinctly observed and its time ascertained. The continents and seas would be seen to disappear in succession at one side and to reappear at the other, and to pass across the disk of the earth as carried round by the diurnal rotation.

210. **Why the full disk of the moon is faintly visible near new moon.**—Soon after conjunction, when the moon appears as a thin crescent, but is so removed from the sun as to be seen at a sufficient altitude after sunset, the entire lunar disk appears faintly illuminated within the horns of the crescent. This phenomenon is explained by the effect of the earth shining upon the moon, and illuminating it by reflected light as the moon illuminates the earth, but with a degree of intensity greater in the ratio of about 14 to 1. According to what has just been explained, the earth appears to the moon nearly full at the time when the moon appears to the earth as a thin crescent, and it therefore receives then the strongest possible illumination. As the lunar crescent increases in breadth, the phase of the earth as seen from the moon becomes less and less full, and the intensity of the illumination is proportionately diminished.

* *See* Chapter on the tides and trade winds.

Hence we find, that as the lunar crescent passes gradually to the quarter, the complement of the lunar disk becomes gradually more faintly visible, and soon disappears altogether.

211. **Physical condition of the moon's surface.**—If we examine the moon carefully, even without the aid of a telescope, we shall discover upon it distinct and definite lineaments of light and shadow. These features never change; there they remain, always in the same position upon the visible orb of the moon. Thus the features that occupy its centre now, have occupied the same position throughout all human record. We have already stated that the first and most obvious inference which this fact suggests, is that the same hemisphere of the moon is always presented towards the earth, and consequently, the other hemisphere is never seen. This singular characteristic which attaches to the motion of the moon round the earth, seems to be a general characteristic of all other moons in the system. Sir William Herschel, by the aid of his powerful telescopes, observed indications which render it probable that the moons of Jupiter revolve in the same manner, each presenting continually the same hemisphere to the planet. The cause of this peculiar motion has been attempted to be explained by the hypothesis that the hemisphere of the satellite which is turned toward the planet, is very elongated and protuberant, and it is the excess of its weight which makes it tend to direct itself always toward the primary, in obedience to the universal principle of attraction. Be this as it may, the effect is, that our selenographical knowledge is necessarily limited to that hemisphere which is turned toward us.

But what is the condition and character of the surface of the moon? What are the lineaments of light and shade which we see upon it? There is no object outside the earth with which the telescope has afforded us such minute and satisfactory information.

If, when the moon is a crescent, we examine with a telescope, even of moderate power, the concave boundary, which is that part of the surface where the enlightened hemisphere ends and the dark hemisphere begins, we shall find that this boundary, is not an even and regular curve, which it undoubtedly would be if the surface were smooth and regular, or nearly so. If, for example, the lunar surface resembled in its general characteristics that of our globe, supposing that the entire surface is land, having the general characteristics of the continents of the earth, the inner boundary of the lunar crescent would still be a regular curve broken or interrupted only at particular points. Where great mountain ranges, like those of the Alps, the Andes, or the Himalaya, might chance to cross it, these lofty peaks would project vastly elongated shadows along the adjacent plains; for it will be remembered that, being

situated, at the moment in question, at the boundary of the enlightened and darkened hemispheres, the shadows would be those of evening or morning; which are prodigiously longer than the objects themselves. The effect of these would be to cause gaps or irregularities in the general outline of the inner boundary of the crescent. With these rare exceptions, the inner boundary of the crescent produced by a globe like the earth would be an even and regular curve.

Such, however, is not the case with the inner boundary of the lunar crescent, even when viewed by the naked eye, and still less so when magnified by a telescope.

It is found, on the contrary, rugged and serrated, and brilliantly illuminated points are seen in the dark parts at some distance from it, while dark shadows of considerable length appear to break into the illuminated surface. The inequalities thus apparent indicate singular characteristics of the surface. The bright points seen within the dark hemisphere are the peaks of lofty mountains tinged with the sun's light. They are in the condition with which all travellers in Alpine countries are familiar; after the sun has set, and darkness has set in over the valleys at the foot of the chain, the sun still continues to illuminate the peaks above.

The sketch of the lunar crescent given in *fig.* 51, being a representation of the moon when visible in the east, shortly before sunrise, and about two days previously to conjunction with the sun, will illustrate these observations.

Fig. 51.

The visible hemisphere of our satellite has, within the last quarter of a century, been subjected to the most rigorous examination which unwearied industry, aided by the vast improvement which has been effected in the instruments of telescopic observation, rendered possible; and it is no exaggeration now to state that we possess a chart of that hemisphere which in accuracy of detail far exceeds any similar representation of the earth's surface.

Among the selenographical observers, the Prussian astronomers, MM. Beer and Mädler, stand pre-eminent. Their descriptive work, entitled *Der Mond*, contains the most complete collection of observations on the

physical condition of our satellite, and the chart, measuring 3; inches in diameter, exhibits the most complete representation o the lunar surface extant. Besides this great work, a selenographi chart was produced by Mr. Russell, from observations made witl a seven-foot reflector, a similar delineation by Lohrmann, and lastly, a very complete model in relief of the visible hemisphere b Madame Witte, an Hanoverian lady.

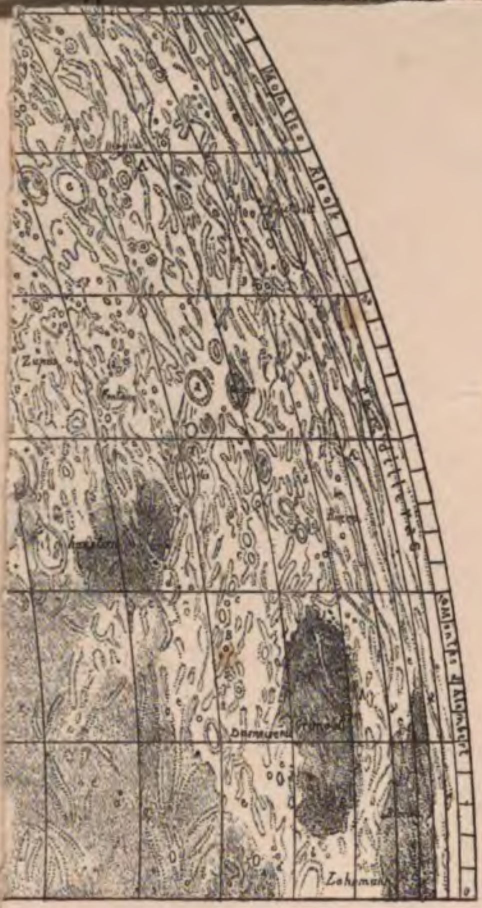
To convey to the student any precise or complete idea of the mas of information collected by the researches and labours of thes eminent observers, would be altogether incompatible with th necessary limits of a work like that which we have undertaken We shall therefore confine ourselves to a selection from some o the most remarkable results of those works, aided by the telescopi chart of the south-eastern quadrant of the moon's disk, given i Plate I., which has been reduced from the great chart of Beer an Mädler, the scale being exactly one half of that of the original.

212. General Description of the Moon's Surface.

(*a*) *Description of the chart, Plate I.* — The entire surface of the visibl hemisphere of the moon is thickly covered with mountainous masses an ranges of various forms, magnitudes, and heights, in which, however, th prevalence of a circular or crater-like form is conspicuous. The mere in spection of the chart of the S.E. quadrant, Plate I., will render this evident and the other three quadrants of the disk do not differ from this in thei general character.*

(*b*) *Causes of the tints of white and grey on the moon's disk.* — The variou tints of white and grey which mark the lineaments observed upon the dis of the full moon arise partly from the different reflecting powers of th matter composing different parts of the lunar surface, and partly from th

* It must be observed that the chart represents the moon's disk as it i seen on the south meridian in an astronomical telescope. As that instru ment produces an inverted image, the south pole appears at the highest an the north pole at the lowest point of the disk, and the eastern limit is o the right and the western on the left of the observer, all of which position are the reverse of those which the same points have when viewed without telescope, or with one which does not invert. The longitudes are measure east and west of the meridian which bisects the visible disk. The origina chart is engraved in four separate sheets, each representing a quadrant o the visible hemisphere. The names of the various selenographical region and more prominent mountains are indicated on the chart, and have bee taken generally from those of eminent scientific men. The meridians draw on the chart divide the surface into zones, each of which measures five de grees of longitude, and the parallels to the equator divide it into zones having each the width of five degrees of latitude. The moon's diamete being less than that of the earth in the ratio of about 21 to 79, a degree o lunar latitude is less than 60 geographical miles in the same proportion, an is, therefore, equal to 16 geographical miles. This supplies a scale by whic the magnitudes on the chart, Plate I., may be approximately estimated.


50
60
70
80

[redacted]

different angles at which the rays of the solar light are incident upon them. If the surface of the lunar hemisphere were uniformly level, or nearly so, these angles of incidence would be determined by the position of each point with relation to the centre of the illuminated hemisphere; and, in that case, the tints would be more regular and would vary in relation principally to the centre of the disk; but, owing to the great inequalities of level, and the vast and complicated mountainous masses which project from every part of the surface, and the great depths of the cavities and plains which are surrounded by the circular mountain ranges, the angles of incidence of the solar rays are subject to extreme and irregular variation, which produce those lineaments and forms tinted with various shades of grey and white with which every eye is familiar.

(*c*) *Shadows visible only in the phases — they supply measures of heights and depths.*— When the moon is full, no shadows upon it can be seen, because, in that position, the visual ray coinciding with the luminous ray, each object is directly interposed between the observer and its shadow. As the phases progress, however, the shadows gradually come into view, because the visual ray is inclined at a gradually increasing angle to the solar ray, and, in the quarters, this angle having increased to 90°, and the boundary of the enlightened hemisphere being then in the centre of the hemisphere presented to the observer, the position is most favourable for the observation of the shadows by which chiefly, not only the forms and dispositions of the mountainous masses and the intervening and enclosed valleys and ravines are ascertained, but their heights and depths are measured. This latter problem is solved by the well-understood principles of geometrical projection when the directions of the visual and solar rays, the position of the object, and of the surface on which the shadows are projected, are severally given.

(*d*) *Uniform patches, called oceans, seas, &c., proved to be irregular land surface.*— Uniform patches of greater or less extent, each having an uniform grey tint more or less dark, having been supposed, by early observers, to be large collections of water, were designated by the names, OCEANUS, MARE, PALUS, LACUS, SINUS, &c. These names are still retained, but the increased power of the telescope has proved that such regions are diversified, like the rest of the lunar surface, by inequalities and undulations of permanent forms, and are therefore not, as was imagined, water or other liquid. They differ from other regions only in the magnitude of the mountain masses which prevail upon them. About two-thirds of the visible hemisphere of the moon consists of this character of surface. Examples of these are presented by the Mare Nubium, Oceanus Procellarum, Mare Humorum, &c., on the chart.

(*e*) *Whiter spots, mountains.*— The more intensely white parts are mountains of various magnitude and form, whose height, relatively to the moon's magnitude, greatly exceeds that of the most stupendous terrestial eminences; and there are many, characterised by an abruptness and steepness which sometimes assume the position of a vast vertical wall, altogether without example upon the earth. These are generally disposed in broad masses, lying in close contiguity, and intersected with vast and deep valleys, gullies, and abysses, none of which, however, have any of the characters which betray the agency of water.

(*f*) *Classes of circular mountain ranges.*— Circular ranges of mountains which, were it not for their vast magnitude, might be inferred from their form to have been volcanic craters, are by far the most prevalent arrange-

ment. These have been denominated, according to their magnitudes, Bu-WARK PLAINS, RING MOUNTAINS, CRATERS, and HOLES.

(*g*) ***Bulwark plains.***— These are circular areas, varying from 40 to 1 miles in diameter, enclosed by a ring of mountain ridges, mostly continuo but in some cases intersected at one or more points by vast ravines. T enclosed area is generally a plain on which mountains of less height a often scattered. The surrounding circular ridge also throws out spurs, bo externally and internally, but the latter are generally shorter than the fo mer. In some cases, however, internal spurs, which are diametrically o posed, unite in the middle so as to cut in two the enclosed plain. In so rare cases the enclosed plain is uninterrupted by mountains, and it is alm invariably depressed below the general level of the surrounding land. A fe instances are presented of the enclosed plain being convex.

The mountainous circle enclosing these vast areas is seldom a sing ridge. It consists more generally of several concentric ridges, one of whic however, always dominates over the rest and exhibits an unequal summ broken by stupendous peaks, which here and there shoot up from it to va heights. Occasionally it is also interrupted by smaller mountains of t circular form.

Examples of bulwark plains are presented in the cases of Clavius, Walte Regiomontanus, Purbach, Alphons, and Ptolemäus.

The diameter of Clavius is 124 miles *, and the enclosed area is 12,0 square miles. One of the peaks of the surrounding ridge shoots up to t height of 16,000 feet.

The diameter of Ptolemäus is 100 miles, and it encloses an area of 64 square miles. This area is intersected by numerous small ridges, not abo a mile in breadth and 100 feet in height. Ptolemäus is surrounded b very high mountains, and is remarkable for the precipitous character of i inner sides.

The other bulwark plains above named have nearly the same characte but less dimensions.

(*h*) ***Ring mountains.***—These circular formations are on a smaller sca than the bulwark plains, varying from 10 to 50 miles in diameter, and th are generally more regular and more exactly circular in their form. Th are sometimes found upon the ridge which encloses a bulwark plain, th interrupting the continuity of its boundary, and sometimes they are se within the enclosed area. Sometimes they stand in the midst of the *mari* Their inner declivity is always steep, and the enclosed area, which is alwa concave, often includes a central mountain, presenting thus the gener character of a volcanic crater, but on a scale of magnitude without examp in terrestrial volcanoes. The surface enclosed is always lower than t region surrounding the enclosing ridge, and the central mountain often ris to such a height that, if it were levelled, it would fill the depression.

(*i*) ***Tycho, a ring mountain.*** — The most remarkable example of this cla is Tycho (see chart, lat. 42° long. 12°). This object is distinguishab without a telescope on the lunar disk when full; but, owing to the multitu of other features which become apparent around it in the phases, it can the be only distinguished by a perfect knowledge of its position, and with a goo telescope. The enclosed area, which is very nearly circular, is 47 miles i

* The geographical mile, or the sixtieth part of a degree of the earth meridian.

XII

PHOTOGRAVURE GILLOT QUAI ST MICHEL 28 PARIS

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diameter, and the inside of the enclosing ridge has the steepness of a wall. Its height above the level of the enclosed plain is 16,000 feet, and above that of the external regions 12,000 feet. There is a central mount, height 4700 feet, besides a few lesser hills within the enclosure.

(*k*) *Craters and holes.*— These are the smallest formations of the circular class. Craters enclose a visible area, containing generally a central mound or peak, exhibiting in a striking manner the volcanic character. Holes include no visible area, but may possibly be craters on a scale too small to be distinguished by the telescope.

Formations of this class are innumerable on every part of the visible surface of the moon, but are no where more prevalent than in the region around Tycho, which may be seen on a very enlarged scale in Plate XI., which represents that ring mountain and the adjacent region, extending over sixteen degrees of latitude, and from sixteen to twenty degrees of longitude.

(*l*) *Other mountain formations.*— Besides the preceding, which are the most remarkable, the most characteristic, and the most prevalent, there are various other forms of mountain, classified by Beer and Mädler, but which our limits compel us to omit.

(*m*) *Singular and unexplained optical phenomenon of radiating streaks.*— Among the most remarkable phenomena presented to lunar observers, is the systems of streaks of light and shade, which radiate from the borders of some of the largest of the ring mountains, spreading to distances of several hundred miles around them. Seven of the mountains of this class, viz., Tycho, Copernicus, Kepler, Proclus, Anaxagoras, Aristarchus, and Olbers are severally the centres round which this extraordinary radiation is manifested. Similar phenomena, less conspicuously developed, however, are visible around Mayer, Euler, Aristillus, Timocharis, and some others.

These phenomena, as displayed when the moon is full around Tycho, are represented in Plate XII. on the same scale as Plate XI.

These radiating streaks commence at a distance of about 20 miles outside the circular ridge of Tycho. From that limit they diverge and overspread fully a fourth part of the visible hemisphere. On the S. they extend to the edge of the disk; on the E. to Hainzel and Capuanus; on the S.E. to the Mare Nubium; on the N. to Alphons; on the N.W. to the Mare Nectaris, and to the W., so as to cover nearly the entire south-western quadrant.

They are only visible when the sun's rays fall upon the region of Tycho at an incidence greater than 25°, and the more perpendicularly the rays fall upon it, the more fully developed the phenomena will be. They are, therefore, only seen in their splendour, as represented in Plate XII., when the moon is full. As the moon moves from opposition to the last quarter, the streaks therefore gradually disappear, and the shadows of the mountain formations are at the same time gradually brought into view, so that the aspect of the moon undergoes a complete transformation. This change may be very well exhibited by holding the Plate XII. before a window to which the back of the observer is turned. He will then see the phenomena as they are presented on the full moon. Let him then turn slowly upon his heel until his face is presented to the window, holding the paper between his eyes and the light. The Plate XI. will then be seen by means of the transparency of the paper, and it will gradually become more and more distinctly apparent as he turns more directly towards the light.*

* This ingenious expedient is suggested by Mädler. It must be remem-

Although the mountain formations generally disappear under the splendour of these radiating streaks, some few, as will be perceived on Plate XII., continue to be visible through them.

None of the numerous selenographic observers have proposed any satisfactory explanation of these phenomena, which are exhibited nearly in the same manner around the other ring mountains above named. Schröter supposed them to be mountains, an hypothesis overturned by the observations since made with more powerful instruments. Herschel, the elder, suggested the idea of streams of lava; Cassini imagined they might be clouds; and others even suggested the possibility of their being roads! Mädler imagines that these ring mountains may have been among the first selenological formations; and, consequently, the points to which all the gases evolved in the formation of our satellite would have been attracted. These emanations produced effects, such as vitrification or oxydation, which modified the reflective powers of the surface. We must, however, dismiss these conjectures, however ingenious and attractive, referring those who desire to pursue the subject to the original work.

(*n*) *Environs of Tycho.*— This region is crowded with hundreds of peaks, crests, and craters (see Plate XI.); not the least vestige of a plain can anywhere be discovered. Towards the E. and S.E. craters predominate, while to the W. chains parallel to the ring are more numerous. On the S. the mountains are thickly scattered in confused masses. At a distance of 15 to 25 miles, craters and small ring mountains are seen, few being circular, but all approaching to that form. All are surrounded by steep ramparts.

(*o*) *Wilhelm I.*— This is a considerable ring mountain S.E. of Tycho. The altitude of its eastern parapet is 10,000 feet, that of its western being only 6000. Its crest is studded with peaks; and craters of various magnitudes, heights, and depths, surrounding it in great numbers, and giving a varied appearance to the adjacent region.

(*p*) *Longomontanus.* — A large circular range, having a diameter of 80 miles, enclosing a plain of great depth. The eastern and western ridges rise to the height of 12,000 to 13,000 feet above the level of the enclosed plain. Its shadow sometimes falls upon and conceals the numerous craters and promontories which lie near it. The whole surrounding region is savage and rugged in the highest degree, and must, according to Mädler, have resulted from a long succession of convulsions. The principal, and apparently original, crater has given way in course of time to a series of new and less violent eruptions. All these smaller formations are visible on the full moon, but not the principal range, which then disappears, though its place may still be ascertained by its known position in relation to Tycho.

(*q*) *Maginus.* — This range N.W. of Tycho (see Plate I.) has the appearance of a vast and wild ruin. The wide plain enclosed by it lies in deep shade even when the sun has risen to the meridian. Its general height is 13,000 feet. A broad elevated base connects the numberless peaks, terraces, and groups of hills constituting this range, and small craters are numerous among these wild and confused masses. The central peak A is a low but

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bered, however that, while Plate XI. represents the region as it appears in a telescope which inverts, Plate XII., represents it as if it were reflected in a mirror, or as it would be seen with a telescope having a prismatic eye-piece.

XIII.

PLAN OF THE LUNAR MOUNTAIN GASSENDI, BY MÄDLER.

From observations with the Dorpat Telescope.

well-defined hill, close to which is a crater-like depression, and other less considerable hills.

(*r*) *Analogy to terrestrial volcanoes more apparent than real — enlarged view of Gassendi.*— The volcanic character observed in the selenographic formation loses much of its analogy to like formations on the earth's surface when higher magnifying powers enable us to examine the details of what appear to be craters, and to compare their dimensions with even the most extensive terrestrial craters. Numerous examples may be produced to illustrate this. We have seen that Tycho, which, viewed under a moderate magnifying power, appears to possess in so eminent a degree the volcanic character, is, in fact, a circular chain enclosing an area upwards of fifty miles in diameter. Gassendi, another system of like form, and of still more stupendous dimensions, is delineated in Plate XIII., as seen with high magnifying powers. This remarkable object consists of two enormous circular chains of mountains, the lesser, which lies to the north, measuring 16½ miles in diameter, and the greater, lying to the south, enclosing an area 60 miles in diameter. The area enclosed by the former is therefore 214, and by the latter 2827 square miles. The height of the lesser chain is about 10,000 feet, while that of the greater varies from 3500 to 5000 feet. The vast area thus enclosed by the greater chain includes, at or near its centre, a principal central mountain, having eight peaks and an height of 2000 feet, while scattered over the surrounding enclosure upwards of a hundred mountains of less considerable elevation have been counted.

It is easy to see how little analogy to a terrestrial volcanic crater is presented by these characters.

The preceding selections, combined with the charts, Plates I., XI., XII., and XIII., will serve to show the general physical character of the lunar surface, and the elaborate accuracy with which it has been submitted to telescopic examination. In the work of Beer and Mädler a table of the heights of above 1000 mountains is given, several of which attain to an elevation of 23,000 feet, equal to that of the highest summits of terrestrial mountains, while the diameter of the moon is little more than a quarter that of the earth.

213. **Observations of Herschel.** — Sir John Herschel says, that among the lunar mountains may be observed in its highest perfection the true volcanic character, as seen in the crater of Vesuvius and elsewhere; but with the remarkable peculiarity that the bottoms of many of the craters are very deeply depressed below the general surface of the moon, the internal depth being in many cases two or three times the external height. In some cases, he thinks, decisive marks of volcanic stratification, arising from a succession of deposits of ejected matter, and evident indications of currents of lava streaming outwards in all directions, may be clearly traced with powerful telescopes.

214. **Observations of the Earl of Rosse.** — By means of the great reflecting telescope of Lord Rosse, the flat bottom of the crater called Albategnius is distinctly seen to be strewed with

blocks, not visible with less powerful instruments; while the exterior of another (Aristillus) is intersected with deep gullies radiating from its centre.

215. **Supposed influence of the moon on the weather.**—Among the many influences which the moon is supposed, by the world in general, to exercise upon our globe, one of those, which has been most universally believed, in all ages and in all countries, is that which it is presumed to exert upon the changes of the weather. Although the particular details of this influence are sometimes pretended to be described, the only general principle, or rule, which prevails with the world in general is, that a change of weather may be looked for at the epochs of new and full moon: that is to say, if the weather be previously fair it will become foul, and if foul will become fair. Similar changes are also, sometimes, though not so confidently, looked for at the epochs of the quarters.

A question of this kind may be regarded either as a question of science, or a question of fact.

If it be regarded as a question of science, we are called upon to explain how and by what property of matter, or what law of nature or attraction, the moon, at a distance of a quarter of a million of miles, combining its effects with the sun, at four hundred times that distance, can produce those alleged changes. To this it may be readily answered that no known law or principle has hitherto explained any such phenomena. The moon and sun must, doubtless, affect the ocean of air which surrounds the globe, as they affect the ocean of water—producing effects analogous to tides; but when the quantity of such an effect is estimated, it is proved to be such as could by no means account for the meteorological changes here adverted to.

But in conducting investigations of this kind we proceed altogether in the wrong direction, and begin at the wrong end, when we commence with the investigation of the physical cause of the supposed phenomena. Our first business is carefully and accurately to observe the phenomena of the changes of the weather, and then to put them in juxtaposition with the contemporaneous changes of the lunar phases. If there be any discoverable correspondence, it then becomes a question of physics to assign its cause.

Such a course of observation has been made in various observatories with all the rigour and exactitude necessary in such an inquiry, and has been continued over periods of time so extended, as to efface all conceivable effects of accidental irregularities.

We can imagine, placed in two parallel columns, in juxtaposition, the series of epochs of the new and full moons, and the quarters, and the corresponding conditions of the weather at these times, for fifty or one hundred years back, so that we may be enabled to ex-

amine, as a mere matter of fact, the conditions of the weather for one thousand or twelve hundred full and new moons and quarters.

From such a mode of observation and inquiry, it has resulted conclusively that the popular notions concerning the influence of the lunar phases on the weather have no foundation in theory, and no correspondence with observed facts. That the moon, by her gravitation, exerts an attraction on our atmosphere cannot be doubted; but the effects which that attraction would produce upon the weather are not in accordance with observed phenomena; and, therefore, these effects are either too small in amount to be appreciable in the actual state of meteorological instruments, or they are obliterated by other more powerful causes, from which hitherto they have not been eliminated. It appears, however, by some series of observations, not yet confirmed or continued through a sufficient period of time, that a slight correspondence may be discovered between the periods of rain and the phases of the moon, indicating a very feeble influence, depending on the relative position of that luminary to the sun, but having no discoverable relation to the lunar attraction. This is not without interest as a subject of scientific inquiry, and is entitled to the attention of meteorologists; but its influence is so feeble that it is altogether destitute of popular interest as a weather prognostic. It may, therefore, be stated that, as far as observation combined with theory has afforded any means of knowledge, there are no grounds for the prognostications of weather erroneously supposed to be derived from the influence of the sun and moon.

Those who are impressed with the feeling that an opinion so universally entertained even in countries remote from each other, as that which presumes an influence of the moon over the changes of the weather, will do well to remember that against that opinion we have not here opposed mere theory. Nay, we have abandoned for the occasion the support that science might afford, and the light it might shed on the negative of this question, and have dealt with it as a mere question of fact. It matters little, so far as this question is concerned, in what manner the moon and sun may produce an effect on the weather, nor even whether they be active causes in producing such effect at all. The point, and the only point of importance, is, whether, regarded as a mere *matter of fact*, any correspondence between the changes of the moon and those of the weather exists? And a short examination of the recorded facts proves that IT DOES NOT.

216. **Other supposed lunar influences.**—But meteorological phenomena are not the only effects imputed to our satellite: that body, like comets, is made responsible for a vast variety of interferences with organised nature. The circulation of the juices of

vegetables, the qualities of grain, the fate of the vintage, are all laid to its account; and timber must be felled, the harvest cut down and gathered in, and the juice of the grape expressed, at times and under circumstances regulated by the aspects of the moon, if excellence be hoped for in these products of the soil.

According to popular belief, our satellite also presides over human maladies; and the phenomena of the sick chamber are governed by the lunar phases; nay, the very marrow of our bones, and the weight of our bodies, suffer increase or diminution by its influence. Nor is its imputed power confined to physical or organic effects; it notoriously governs mental derangement.

If these opinions respecting lunar influences were limited to particular countries, they would be less entitled to serious consideration; but it is a curious fact that many of them prevail and have prevailed in quarters of the earth so distant and unconnected, that it is difficult to imagine the same error to have proceeded from the same source.

Our limits, and the objects to which this volume is directed, render it impossible here to notice more fully the physical and physiological influences imputed to the moon, more especially as these influences, though interesting in themselves, have but an indirect connection with lunar astronomy.

217. **The lunar theory.**—It is the object of this work to present to the reader in as concise a form as possible, a general description of the celestial motions peculiar to each member of the solar system, without adding to the text symbolical explanations where they can easily be avoided; those of our readers who desire to enter largely into the theoretical branch of lunar astronomy should, therefore, consult those works which are more particularly devoted to the subject. At the present moment some of our greatest mathematicians are, not only in England, but also in France and Germany, discussing several of the most difficult portions of the lunar theory, bringing to their aid the highest mathematical analysis in the power of the human intellect. The publication of the reductions of the Greenwich observations of the moon made since 1750 up to a modern date, has to a great extent been the origin of all these important investigations. As one great result, Professor Hansen of Gotha, using these observations for the perfection of the theory, has formed lunar tables, which from their general agreement with a considerable number of modern observations, with which they have been compared, are considered worthy of being classed amongst the greatest triumphs of theoretical astronomy.

CHAPTER XI.

THE TIDES AND TRADE WINDS.

218. **Correspondence between the recurrence of the tides and the diurnal appearance of the moon.** — The phenomena of the tides of the ocean are too remarkable not to have attracted notice at an early period in the progress of knowledge. The intervals between the epochs of high and low water everywhere corresponding with the intervals between the passage of the moon over the meridian above and below the horizon, suggested naturally the physical connection between these two effects, and indicated the probability of the cause of the tides being found in the motion of the moon.

219. **Erroneous notions of the lunar influence.** — There are few subjects in physical science about which more erroneous notions prevail among those who are but a little informed. A common idea is, that the attraction of the moon draws the waters of the earth toward that side of the globe on which it happens to be placed, and that consequently they are heaped up on that side, so that the oceans and seas acquire there a greater depth than elsewhere; and that high water will thus take place under, or nearly under, the moon. But this does not correspond with the fact. High water is not produced merely under the moon, but is equally produced upon those parts most removed from the moon. Suppose a meridian of the earth so selected, that if it were continued beyond the earth, its plane would pass through the moon; we find that, subject to certain modifications, a great tidal wave, or what is called *high water*, will be formed on both sides of this meridian; that is to say, on the side next the moon, and on the side remote from the moon. As the moon moves, these two great tidal waves follow her. They are of course separated from each other by half the circumference of the globe. As the globe revolves with its diurnal motion upon its axis, every part of its surface passes successively under these tidal waves; and at all such parts, as they pass under them, there is the phenomenon of high water. Hence it is that in all places there are two tides daily, having an interval of about twelve hours between them. Now, if the common notion of the cause of the tides were well founded, there would be only one tide daily — viz., that which would take place when the moon is at or near the meridian.

220. **The moon's attraction alone will not explain the tides.** — That the moon's attraction upon the earth simply considered

would not explain the tides is easily shown. Let us suppose that the whole mass of matter on the earth, including the waters which partially cover it, were attracted equally by the moon; they would then be equally drawn toward that body, and no reason would exist why they should be heaped up under the moon; for if they were drawn with the same force as that with which the solid globe of the earth under them is drawn, there would be no reason for supposing that the waters would have a greater tendency to collect toward the moon than the solid bottom of the ocean on which they rest. In short, the whole mass of the earth, solid and fluid, being drawn with the same force, would equally tend toward the moon; and its parts, whether solid or fluid, would preserve among themselves the same relative position as if they were not attracted at all.

221. **Tides caused by the difference of the attractions on different parts of the earth.** — When we observe, however, in a mass composed of various particles of matter, that the relative arrangement of these particles is disturbed, some being driven in certain directions more than others, the inference is, that the component parts of such a mass must be placed under the operation of different forces: those which tend more than others in a certain direction being driven with a proportionally greater force. Such is the case with the earth, placed under the attraction of the moon. And this is, in fact, what must happen under the operation of an attractive force like that of gravitation, which diminishes in its intensity as the square of the distance increases.

Let A, B, C, D, E, F, G, H, *fig.* 52, represent the globe of the earth, and, to simplify the explanation, let us first suppose the entire surface of the globe to be covered with water. Let M, the moon, be placed at the distance M H from the nearest point of the

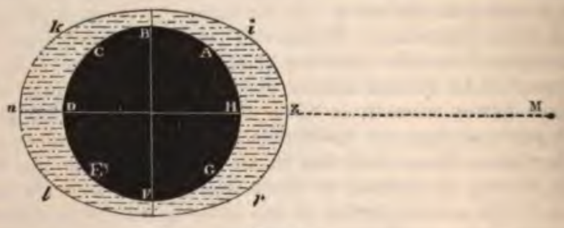

Fig. 52.

surface of the earth. Now it will be apparent that the various points of the earth's surface are at different distances from the moon M. A and G are more remote than H; B and F still more re-

mote; C and E more distant again, and D more remote than all. The attraction which the moon exercises at H is, therefore, greater than that which it exercises at A and G, and still greater than that which it produces at B and F; and the attraction which it exercises at D is least of all. Now this attraction equally affects matter in every state and condition. It affects the particles of fluid as well as solid matter; but there is this difference, that where it acts upon solid matter, the component parts of which are at different distances from it, and therefore subject to different attractions, it will not disturb the relative arrangement, since such disturbances or disarrangements are prevented by the cohesion which characterises a solid body; but this is not the case with fluids, the particles of which are mobile.

The attraction which the moon exercises upon the shell of water, which is collected immediately under it near the point Z, is greater than that which it exercises upon the solid mass of the globe; consequently there will be a greater tendency of this attraction to draw the fluid which rests upon the surface at H toward the moon, than to draw the solid mass of the earth which is more distant.

As the fluid, by its nature, is free to obey this excess of attraction, it will necessarily heap itself up in a pile or wave over H, forming a convex protuberance, as represented between *r* and *i*. Thus high water will take place at H, immediately under the moon. The water which thus collects at H will necessarily flow from the regions B and F, where therefore there will be a diminished quantity in the same proportion.

But let us now consider what happens to that part of the earth D. Here the waters, being more remote from the moon than the solid mass of the earth under them, will be less attracted, and consequently will have a less tendency to gravitate toward the moon. The solid mass of the earth, D H, will, as it were, recede from the waters at *n*, in virtue of the excess of attraction, leaving these waters behind it, which will thus be heaped up at *n*, so as to form a convex protuberance between *l* and *k*, similar exactly to that which we have already described between *r* and *i*. As the difference between the attraction of the moon on the waters at Z and the solid earth under the waters is nearly the same as the difference between its attraction on the latter and upon the waters at *n*, it follows that the height of the fluid protuberances at Z and *n* are equal. In other words, the height of the tides on opposite sides of the earth, the one being under the moon and the other most remote from it are equal.

It appears, therefore, that the cause of the tides, so far as the action of the moon is concerned, is not, as is vulgarly supposed,

the mere attraction of the moon; since, if that attraction were equal on all the component parts of the earth, there would assuredly be no tides. We are to look for the cause, not in the attraction of the moon, but in the *inequality* of its attraction on different parts of the earth. The greater this inequality is, the greater will be the tides. Hence, as the moon is subject to a slight variation of distance from the earth, it will follow, that when it is at its least distance, or at the point called *perigee*, the tides will be greatest; and when it is at the greatest distance, or at the point called *apogee*, the tides will be least; not because the entire attraction of the moon in the former case is greater than in the latter, but because the diameter of the globe bearing a greater proportion to the lesser distance than the greater, there will be a greater *inequality* of attraction.

222. **Effects of sun's attraction.**—It will occur to those who bestow on these observations a little reflection, that all which we have stated in reference to the effects produced by the attraction of the moon upon the earth, will also be applicable to the attraction of the sun. This is undoubtedly true; but in the case of the sun the effects are modified in some very important respects. The sun is at 400 times a greater distance than the moon, and the actual amount of its attraction on the earth would, on that account, be 160,000 times less than that of the moon; but the mass of the sun exceeds that of the moon in a much greater ratio than that of 160,000 to 1. It therefore possesses a much greater attracting power in virtue of its mass, compared with the moon, than it loses by its greater distance. It exercises, therefore, upon the earth an attraction enormously greater than the moon exercises. Now, if the simple amount of its attraction were, as is commonly supposed, the cause of the tides, the sun ought to produce a vastly greater tide than the moon. The reverse is, however, the case, and the cause is easily explained. Let it be remembered that the tides are due solely to the inequality of the attraction on different sides of the earth, and the greater that inequality is, the greater will be the tides, and the less that inequality is, the less will be the tides.

In the case of the sun, the total distance is 12,000 diameters of the earth, and consequently the difference between its distances from the one side and the other of the earth will be only the 12,000th part of the whole distance, while in the case of the moon, the total distance being only 30 diameters of the earth, the difference of the distances from one side and the other is the 30th part of the whole distance. The inequality of the attraction, upon which *alone*, and not on its whole amount, the production of the tidal wave depends, is therefore much greater in the case of the moon.

According to Newton's calculation, the tidal wave due to the moon is greater in height than that due to the sun in the ratio of 58 to 23, or $2\frac{1}{2}$ to 1 very nearly.

223. **Cause of spring and neap tides.**—There is, therefore, a solar as well as a lunar tide wave, the former being much less elevated than the latter, and each following the luminary from which it takes its name. When the sun and moon, therefore, are either on the same side of the earth, or on the opposite sides of the earth—in other words, when it is new or full moon—their effects in producing tides are combined, and the spring tide is produced, the height of which is equal to the solar and lunar tides taken together.

On the other hand, when the sun and moon are separated from each other by a distance of one fourth of the heavens, that is, when the moon is in the quarters, the effect of the solar tide has a tendency to diminish that of the lunar tide.

The tides produced by the combination of the lunar and solar tide waves at the time of new and full moon are called SPRING TIDES; and those produced by the lunar wave diminished by the effect of the solar wave at the quarters are called NEAP TIDES.

224. **Why the tides are not produced directly under the moon.**—If physical effects followed immediately without any appreciable interval of time the operation of their causes, then the tidal wave produced by the moon would be on the meridian of the earth directly under and opposite to that luminary; and the same would be true of the solar tides. But the waters of the globe have in common with all other matter, the property of inertia, and it takes a certain interval of time, to impress upon them a certain change of position. Hence it follows that the tidal wave produced by the moon is not formed immediately under that body, but follows it at a certain distance. In consequence of this, the tide raised by the moon does not take place for two or three hours after the moon passes the meridian; and as the action of the sun is still more feeble, there is a still greater interval between the transit of the sun and occurrence of the solar tide.

225. **Priming and lagging of the tides.**—But besides these circumstances, the tide is affected by other causes. It is not to the separate effect of either of these bodies, but to the combined effect of both, that the effects are due; and at every period of the month, the time of actual high water is either accelerated or retarded by the sun. In the first and third quarters of the moon, the solar tide is westward of the lunar one; and, consequently, the actual high water, which is the result of the combination of the two waves, will be to the westward of the place it would have if the moon acted alone, and the time of high water will therefore be accelerated. In

the second and fourth quarters the general effect of the sun is, for a similar reason, to produce a retardation in the time of high water. This effect, produced by the sun and moon combined, is what is commonly called the *priming* and *lagging* of the tides. The highest spring tides occur when the moon passes the meridian about an hour after the sun; for then the maximum effect of the two bodies coincides.

226. **Researches of Whewell and Lubbock.**—The subject of the tides has of late years received much attention from several scientific investigators in Europe. The discussions held at the annual meetings of the British Association for the Advancement of Science, on this subject, have led to the development of much useful information. The labours of Professor Whewell have been especially valuable on these questions. Sir John Lubbock has also published a valuable treatise upon it. To trace the results of these investigations in all the details which would render them clear and intelligible, would greatly transcend the necessary limits of this volume. We shall, however, briefly advert to a few of the most remarkable points connected with these questions.

227. **Vulgar and corrected establishment.**—The apparent time of high water at any port in the afternoon of the day of new or full moon, is what is usually called the *establishment of the port.* Professor Whewell calls this the vulgar establishment, and he calls the *corrected establishment* the mean of all the intervals of the tides and transit of half a month. This corrected establishment is consequently the luni-tidal interval corresponding to the day on which the moon passes the meridian at noon or midnight.

228. **Diurnal inequality.**—The two tides immediately following one another, or the tides of the day and night, vary, both in height and time of high water at any particular place, with the distance of the sun and moon from the equator. As the vertex of the tide wave always tends to place itself vertically under the luminary which produces it, it is evident that of two consecutive tides, that which happens when the moon is nearest the zenith or nadir will be greater than the other; and, consequently, when the moon's declination is of the same denomination as the latitude of the place, the tide which corresponds to the upper transit will be greater than the opposite one, and *vice versâ*, the difference being greatest when the sun and moon are in opposition, and in opposite tropics. This is called the DIURNAL INEQUALITY, because its cycle is one day; but it varies greatly at different places, and its laws, which appear to be governed by local circumstances, are very imperfectly known.

229. **Local effects of the land upon the tides.**—We have now described the principal phenomena that would take place were

the earth a sphere, and covered entirely with a fluid of uniform depth. But the actual phenomena of the tides are infinitely more complicated. From the interruption of the land, and the irregular form and depth of the ocean, combined with many other disturbing circumstances, among which are the inertia of the waters, the friction on the bottom and sides, the narrowness and length of the channels, the action of the wind, currents, difference of atmospheric pressure, &c. &c., great variation takes place in the mean times and heights of high water at places differently situated.

230. **Velocity of tidal wave.**—In the open ocean the crest of tide travels with enormous velocity. If the whole surface were uniformly covered with water, the summit of the tide wave, being mainly governed by the moon, would everywhere follow the moon's transit at the same interval of time, and consequently travel round the earth in a little more than twenty-four hours. But the circumference of the earth at the equator being about 25,000 miles, the velocity of propagation would therefore be about 1,000 miles per hour. The actual velocity is, perhaps, nowhere equal to this, and is very different at different places. In latitude 60° south, where there is no interruption from land (excepting the narrow promontory of Patagonia), the tide wave will complete a revolution in a lunar day, and consequently travel at the rate of 670 miles an hour. On examining Dr. Whewell's map of cotidal lines, it will be seen that the great tide wave from the Southern Ocean travels from the Cape of Good Hope to the Azores in about twelve hours, and from the Azores to the southernmost part of Ireland in about three hours more. In the Atlantic, the hourly velocity in some cases appears to be 10° latitude, or near 700 miles, which is almost equal to the velocity of sound through the air. From the south point of Ireland to the north point of Scotland, the time is eight hours, and the velocity about 160 miles an hour along the shore. On the eastern coast of Britain, and in shallower water, the velocity is less. From Buchanness to Sunderland it is about 60 miles an hour; from Scarborough to Cromer, 35 miles; from the North Foreland to London, 30 miles; from London to Richmond 13 miles an hour in that part of the river. (Whewell, *Phil. Trans.* 1833, 1836.) It is scarcely necessary to remind the reader that the above velocities refer to the transmission of the undulation, and are entirely different from the velocity of the current to which the tide gives rise in shallow water.

231. **Range of the tides.**—The difference of level between high and low water is affected by various causes, but chiefly by the configuration of the land, and is very different at different places. In deep inbends of the shore, open in the direction of the tide wave and gradually contracting like a funnel, the convergence of water

causes a very great increase of the range. Hence the very high tides in the Bristol Channel, the Bay of St. Malo, and the Bay of Fundy, where the tide is said to rise sometimes to the height of one hundred feet. Promontories, under certain circumstances, exert an opposite influence, and diminish the magnitude of the tide. The observed ranges are also very anomalous. At certain places on the south-east coast of Ireland, the range is not more than three feet, while at a little distance on each side it becomes twelve or thirteen feet; and it is remarkable that these low tides occur directly opposite the Bristol Channel where (at Chepstow) the difference between high and low water amounts to sixty feet. In the middle of the Pacific it amounts to only two or three feet. At the London Docks, the average range is about 22 feet; at Liverpool, 15·5 feet; at Portsmouth, 12·5; at Plymouth, also 12·5; at Bristol, 33 feet.

232. **Tides affected by the atmosphere.**—Besides the numerous causes of irregularity depending on the local circumstances, the tides are also affected by the state of the atmosphere. At Brest, the height of high water varies inversely as the height of the barometer, and rises more than eight inches for a fall of about half an inch of the barometer. At Liverpool, a fall of one-tenth of an inch in the barometer corresponds to a rise in the river Mersey of about an inch; and at the London Docks, a fall of one-tenth of an inch corresponds to a rise in the Thames of about seven-tenths of an inch. With a low barometer, therefore, the tide may be expected to be high, and *vice versâ*. The tide is also liable to be disturbed by winds. Sir John Lubbock states that, in the violent hurricane on the 8th of January, 1839, there was no tide at Gainsborough, which is twenty-five miles up the Trent—a circumstance unknown before. At Saltmarsh, only five miles up the Ouse from the Humber, the tide went on ebbing, and never flowed until the river was dry in some places; while at Ostend, towards which the wind was blowing, contrary effects were observed. During strong north-westerly gales, the tide marks high water earlier in the Thames than otherwise, and does not give so much water, while the ebb tide runs out late, and marks lower; but upon the gales abating and weather moderating, the tides put in and rise much higher, while they also run longer before high water is marked, and with more velocity of current: nor do they run out so long or so low.

233. **The trade winds.**—The great atmospheric currents thus denominated, from the advantages which navigation has derived from them, as well as other currents arising from the same causes, are produced by the unequal exposure of the atmospheric ocean, which coats the terrestrial globe, to the action of solar heat; the *expansion* and contraction that air, in common with all gaseous

bodies, suffers from increase and diminution of temperature; the tendency which lighter fluids have to rise through heavier; and, lastly, the rotation of the earth upon its axis.

The regions in which the TRADES prevail are two great tropical belts extending through a certain limited number of degrees north and south of the line, but not prevailing on the line itself, the atmospherical character of which is an almost constant calm. The permanent currents blow in the northern tropical belt from the north-east, and in the southern from the south-east.

On the other hand, in the higher latitudes of both hemispheres the prevalent atmospheric currents are directed from west to east, redressing, as it were, the disturbance produced by the trades.

To understand the cause of these phenomena, it is necessary to remember that the sun, never departing more than $23\frac{1}{2}°$ from the celestial equator, is vertical daily to different points around the tropical regions, the rotation of the earth bringing these points successively under his disk. The sun, at noon, for places situated on the equator, is never so much as $23\frac{1}{2}°$ from the zenith, while the extreme zenith distance of the sun at noon, for places within the tropics, can never exceed 47°. The intertropical zone from these causes becomes much more intensely heated upon its surface, than the parts of either hemisphere at higher latitudes. This heat, reflected and radiated upon the incumbent atmosphere, causes it to expand and become specifically lighter, and it ascends as smoke and heated air do in a chimney. The space it deserts is filled by colder and therefore heavier air, which rushes in from the higher parts of either hemisphere; while the air thus displaced, raised by its buoyancy above its due level, and unsustained by any lateral pressure, flows down towards either pole, and, being cooled in its course and rendered heavier, it descends to the surface of the globe at those upper latitudes from which the air had been sucked in towards the line by its previous ascent.

A constant circulation and an interchange of atmosphere between the intertropical and extratropical regions of the earth would thus take place, the air ascending from the intertropical surface and then flowing towards the extratropical regions, where it descends to the surface to be again sucked towards the line.

But in this view of the effects, the rotation of the earth on its axis is not considered. In that rotation the atmosphere participates. The air which rises from the intertropical surfaces carries with it the velocity of that surface, which is at the rate of about 1000 miles an hour from west to east. This velocity it retains to a considerable extent after it has passed to the higher latitudes and descended to the surface, which moving with much less velocity from west to east, there is an effective current produced in that direction,

equivalent to the excess of the eastward motion of the air over the eastward motion of the surface of the earth. Hence arises the prevalent westward winds, especially at sea, where causes of local disturbance are not frequent, which are so familiar, and one of the effects of which has been, that, while the average length of the trip of good sailing vessels from New York to Liverpool has been only twenty days, that of the trip from Liverpool to New York has been thirty-five days.

By the friction of the earth, and other causes, the air, however, next the surface, at length acquires a common velocity with it, and when it is, as above described, sucked towards the line to fill the vacuum produced by the air drawn upwards by the solar heat, it carries with it the motion from west to east which it had, in common with the surface, at the higher latitudes. But the surface at the line has a much greater velocity than this from west to east. The surface, therefore, and all objects upon it, are carried against the air with the *relative velocity* of the surface and the air, that is to say, with the effect of the *difference* of their velocities. Since the surface, and the objects upon it, are carried eastward at a much less rate than the air which has just descended from the higher latitudes, they will strike against the air with a force proportional to the difference of their velocities, and this force will have a direction contrary to that of the motion of the surface, that is to say, from east to west.

But it must be considered that this eastward force, due to the motion of the earth's surface, is combined with the force with which the air moves from the extratropical regions towards the line. Thus, in the northern hemisphere, the force eastward is combined with the motion of the air from north to south, and the resultant of these forces is that north-east current which actually prevails; while, for like reasons, south of the line, the motion of the air from south to north, being combined with the force eastward, produces the south-eastern current which prevails south of the line.

Were any considerable mass of air, as Sir J. Herschel observes, to be *suddenly* transferred from beyond the tropics to the equator, the difference of the rotatory velocities proper to the two situations would be so great, as to produce, not merely a wind, but a tempest of the most destructive violence; and the same observation would be equally applicable to masses of air transported in the contrary direction. But this is not the case; the advance of the air is gradual, and all the while the earth is continually acting on the air, and by the friction of its surface accelerating or retarding its velocity. Supposing its progress to cease at any point, this cause would almost immediately communicate to it the deficient, or deprive it of the *excessive* motion of rotation, after which it would revolve quietly

with the earth and be at relative rest. We have only to call to mind the comparative *thinness* of the coating of air with which the globe is invested (62) and its immense mass, exceeding, as it does the weight of the atmosphere at least 100,000,000 times, to appreciate the absolute command of any extent of territory of the earth over the atmosphere immediately incumbent upon it.

It appears, therefore, that these currents, as they approach the equator on the one side and the other, must gradually lose their force; their exciting cause being the difference of the magnitude of the parallels of latitude; and this difference being evanescent near the line, and very inconsiderable within many degrees of it, the equalising force of the earth above described is allowed to take full effect: but, besides this, the currents directed from the two poles encounter each other at the line, and destroy each other's force. Hence arises the prevalence of those calms which characterise the line.

CHAPTER XII.

THE SUN.

234. **Apparent and real magnitude.**—Owing to the ellipticity of the earth's orbit, the distance of the sun is subject to a periodical variation, which causes, as has been already explained, a corresponding variation in its apparent magnitude. Its greatest apparent diameter, when in perihelion, is $32' \, 36''\cdot4$, or $1956''\cdot4$, and its least apparent magnitude, when in aphelion, is $31' \, 32''$, or $1892''$. Its mean apparent diameter is therefore $1924''\cdot2$.

The real magnitude of the sun may be easily inferred in round numbers from that of the moon. The apparent diameter of the moon being equal in round numbers to that of the sun, and the distance of the sun being 384 times greater than that of the moon, it follows that the real diameter of the sun must be 384 times greater than that of the moon. It must, therefore, be on this supposition 831,000 miles. By methods of calculation susceptible of closer approximation than this, it has been found that the magnitude is 852,900 miles, or $107\frac{3}{4}$ times the diameter of the earth.

The linear value of $1''$ at the distance of the sun, is 443 miles.

235. **Magnitude of the sun illustrated.**—Magnitudes such as that of the sun so far transcend all standards with which the mind is familiar, that some stretch of imagination, and some effort of the understanding, are necessary to form a conception, however imperfect, of them. The expedient which best serves to obtain some adequate idea of them is, to compare them with some

standard, stupendous by comparison with all ordinary magnitudes, yet minute when compared with them.

The earth itself is a globe nearly 8000 miles in diameter. If the sun be represented by a globe nine feet four inches in diameter, the earth would be represented by a globe an inch in diameter. If the orbit of the moon, which measures 478,000 miles in diameter, were filled by a sun, such a sun might be placed within the actual sun, leaving between their surfaces a distance of nearly 200,000 miles. Such a sun, seen from the earth, would have an apparent diameter little more than half the diameter of the actual sun.

236. **Surface and volume.**—Since the surfaces of globes are as the squares, and their volumes as the cubes, of their diameters, it follows that the surface of the sun must be 11,620 times, and its volume 1,252,000 times, greater than those of the earth.

Thus, to form a globe like the sun it would be necessary to roll nearly thirteen hundred thousand globes like the earth into one.

It is found, by considering the bulks of the different planets, that if all the planets and satellites in the solar system were moulded into a single globe, that globe would still not exceed the five-hundredth part of the globe of the sun; in other words, the bulk of the sun is five hundred times greater than the aggregate bulk of all the rest of the bodies of the system.

237. **Its mass and density.**—By methods of calculation and observation, which will be explained hereafter, the ratio of the mass of matter composing the globe of the sun, to the mass of matter composing the earth, has been ascertained to be 315,000 to 1.

By comparing this proportion of the quantities of ponderable matter in the sun and earth with their relative volumes, it will be evident that the mean density of the matter composing the sun must be about four times less than the mean density of the matter composing the earth; for although the volume of the sun exceeds that of the earth in the ratio of 1,252,000 to 1, its weight or mass exceeds that of the earth in the lesser ratio of 315,000 to 1, the latter ratio being four times less than the former. Bulk for bulk, therefore, the sun is four times lighter than the earth.

Since the mean density of the earth from Mr. Baily's determination is 5·67 times that of water (80), it follows that the mean density of the sun is 1·42 times, or about one half, greater than that of water. This value would be increased to 1·64 using the mean density of the earth 6·57, as obtained from the Harton pendulum experiments (81).

From the comparative lightness of the matter composing it,

Herschel infers the probability that an intense heat prevails in its interior, by which its elasticity is reinforced, and rendered capable of resisting the almost inconceivable pressure due to its intrinsic gravitation, without collapsing into smaller dimensions.

238. **Form and rotation — axis of rotation.** — Although to minds unaccustomed to the rigour of scientific research, it might appear sufficiently evident, without further demonstration, that the sun is globular in its form, yet the more exact methods pursued in the investigation of physics demand that we should find more conclusive proof of the sphericity of the solar orb than the mere fact that the disk of the sun is always circular. It is barely possible, however, improbable, that a flat circular disk of matter, the face of which should always be presented to the earth, might be the form of the sun; and indeed there are a great variety of other forms which, by a particular arrangement of their motions, might present to the eye a circular appearance as well as a globe or sphere. To prove, then, that a body is globular, something more is necessary than the mere fact that it always appears circular.

When a telescope is directed to the sun, we discover upon it certain marks or spots, of which we shall speak more fully presently. We observe that these marks, while they preserve the same relative position with respect to each other, move regularly from one side of the sun to the other. They disappear, and continue to be invisible for a certain time, come into view again on the other side, and so once more pass over the sun's disk. This is an effect which would evidently be produced by marks on the surface of a globe, the globe itself revolving on an axis, and carrying these marks upon it. That this is the case, is abundantly proved by the fact that the periods of rotation for all these marks are found to be exactly the same, viz. about twenty-five days and a quarter, or more exactly $25^d\ 7^h\ 48^m$. Such is, then, the time of rotation of the sun upon its axis, and that it is a globe remains no longer doubtful, since a globe is the only body which, while it revolves with a motion of rotation, would always present the circular appearance to the eye. The axis on which the sun revolves is very nearly perpendicular to the plane of the earth's orbit, and the motion of rotation is in the same direction as the motion of the planets round the sun, that is to say, from west to east.

239. **Spots.** — One of the earliest fruits of the invention of the telescope was the discovery of the spots upon the sun; and the examination of these has gradually led to some knowledge of the

physical constitution of the centre of attraction and the common fountain of light and heat of our system.

When we submit a solar spot to telescopic examination, we discover its appearance to be that of an intensely black irregularly shaped patch, generally edged with a penumbral fringe. When watched for a considerable time, it is found to undergo a gradual change in its form and magnitude; at first increasing gradually in size, until it attain some definite limit of magnitude, when it ceases to increase, and soon begins, on the contrary, to diminish; and its diminution goes on gradually, until at length, the bright sides closing in upon the dark patch, it dwindles first to a mere point, and finally disappears altogether. The period which elapses between the formation of the spot, its gradual enlargement, subsequent diminution, and final disappearance, is very various. Some spots appear and disappear very rapidly, while others have lasted for weeks and even for months.

The magnitude of the spots, and the velocities with which the matter composing their edges and fringes moves, as they increase and decrease, are on a scale proportionate to the dimensions of the orb of the sun itself. When it is considered that a space upon the sun's disk, the apparent breadth of which is only a minute, actually measures 26,580 miles, and that spots have been frequently observed, the apparent length and breadth of which have exceeded 2′, the stupendous magnitude of the regions they occupy may be easily conceived.

The velocity with which the luminous matter at the edges of the spots occasionally moves, during the gradual increase or diminution of the spot, has been in some cases found to be enormous. A spot, the apparent breadth of which was 90″, was observed by Mayer to close in about 40 days. Now, the actual linear dimensions of such a spot must have been 39,870 miles, and consequently, the average daily motion of the matter composing its edges must have been 1000 miles, a velocity equivalent to nearly 42 miles an hour.

240. **Cause of the spots — physical state of the sun's surface.** — Two, and only two, suppositions have been proposed to explain the spots. One supposes them to be scoriæ, or dark scales of incombustible matter, floating on the general surface of the sun. The other supposes them to be excavations in the luminous matter which coats the sun, the dark part of the spot being a part of the solid non-luminous nucleus of the sun. In this latter hypothesis it is assumed that the sun is a solid non-luminous globe, covered with a coating of a certain thickness of luminous matter.

That the spots are excavations, and not mere black patches on

the surface, is proved by the following observations: If we select a spot which is at the centre of the sun's disk, having some definite form, such as that of a circle, and watch its changes of appearance, when, by the rotation of the sun, it is carried toward the edge, we find, first, that the circle becomes an oval. This, however, is what would be expected, even if the spot were a circular patch, inasmuch as a circle seen obliquely is foreshortened into an oval. But we find that as the spot moves toward the side of the sun's limb, the black patch gradually disappears, the penumbral fringe on the inside of the spot becomes invisible, while the penumbral fringe on the outside of the spot increases in apparent breadth, so that when the spot approaches the edge of the sun, the only part that is visible is the external penumbral fringe. Now, this is exactly what would occur if the spot were an excavation. The penumbral fringe is produced by the shelving of the sides of the excavation, sloping down to its dark bottom. As the spot is carried toward the edge of the sun, the height of the inner side is interposed between the eye and the bottom of the excavation, so as to conceal the latter from view. The surface of the inner shelving side also taking the direction of the line of vision or very nearly, diminishes in apparent breadth, and ceases to be visible, while the surface of the shelving side next the edge of the sun becoming nearly perpendicular to the line of vision, appears of its full breadth.

In short, all the variations of appearance which the spots undergo, as they are carried round by the rotation of the sun, changing their distances and positions with regard to the sun's centre, are exactly such as would be produced by an excavation, and not at all such as a dark patch on the solar surface would undergo.

241. **Sun invested by two atmospheres, one luminous and the other non-luminous.**—It may be considered then as proved, that the spots on the sun are excavations; and that the apparent blackness is produced by the fact that the part constituting the dark portion of the spot is either a surface totally destitute of light, or by comparison so much less luminous than the general surface of the sun as to appear black. This fact, combined with the appearance of the penumbral edges of the spots, has led to the supposition, advanced by Sir W. Herschel, which appears scarcely to admit of doubt, that the solid opaque nucleus, or globe of the sun, is invested with at least two atmospheres, that which is next the sun being, like our own, non-luminous, and the superior one being that alone in which light and heat are evolved; at all events, whether these strata be in the gaseous state or not, the existence of two such, one placed above the other, the superior one being luminous, seems to be exempt from doubt.

242. **Spots may not be black.**—We are not warranted in assuming that the black portion of the spots are surfaces really deprived of light, for the most intense artificial lights which can be produced, such, for example, as that of a piece of quicklime exposed to the action of the compound blow-pipe, when seen projected on the sun's disk, appear as dark as the spots themselves; an effect which must be ascribed to the infinitely superior splendour of the sun's light. All that can be legitimately inferred respecting the spots, then, is, not that they are destitute of light, but that they are incomparably less brilliant than the general surface of the sun.

243. **Spots variable.**—The prevalence of spots on the sun's disk is both variable and irregular. Sometimes the disk will be completely divested of them, and will continue so for weeks or months; sometimes they will be spread over certain parts of it in profusion. Sometimes the spots will be small, but numerous; sometimes individual spots will appear of vast extent; sometimes they will be manifested in groups, the penumbræ or fringes being in contact.

The duration of each spot is also subject to great and irregular variation. A spot has appeared and vanished in less than twenty-four hours, while some have maintained their appearance and position for nine or ten weeks, or during nearly three complete revolutions of the sun upon its axis.

A large spot has sometimes been observed suddenly to crumble into a great number of small ones.

244. **Prevail generally in two parallel zones.**—The only circumstance of regularity which can be said to attend these remarkable phenomena is their position upon the sun. They are invariably confined to two moderately broad zones parallel to the solar equator, separated from it by a space several degrees in breadth. The equator itself and this space which thus separates the macular zones, are absolutely divested of such phenomena.

Thus, for example, in the latter part of 1836 and the beginning of 1837, when a large number of spots became apparent, their position was such as is represented in *fig.* 53, where E Q represents the sun's equator, and $m\ m'$, $n\ n'$, the northern, and $p\ p'$, $q\ q'$ the southern macular zones.

245. **Observations and drawings of M. Capocci.**—Amongst the numerous astronomers who have devoted much time and attention to this subject, and who have made most important contributions by their observations and researches, we may mention M. Capocci, of Naples, Dr. Pastorff, of Frankfort (on the Oder), Sir John Herschel, M. Schwabe, of Dessau, and Mr. Carrington.

M. Capocci made a series of observations on the spots which were developed on the sun's disk in 1826, when he recognised most of

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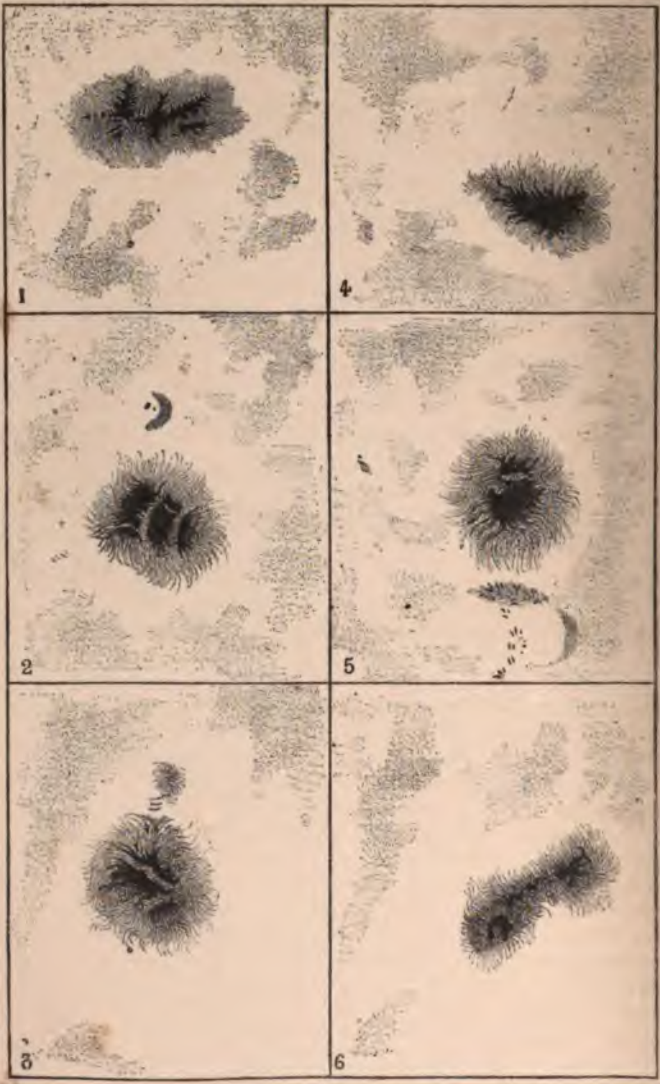


SOLAR SPOTS OBSERVED BY CAPOCCI, 1826.

1. July 2, 10 h. A.M.
2. Sept. 27, 10 h. A.M.
3. Sept. 29, 10 h. A.M.
4. Oct. 2, 10 h. A.M. (1)
5. Oct. 2, 10 h. A.M. (2)
6. Oct. 6, 10 h. A.M.

the characters above described. He observed that, during the increase of the spot from its first appearance as a dark point, the

Fig. 53.

edges were sharply defined, without any indication of the gradually fading away of the fringes into the dark central spot, or into each other; a character which was again observed by Sir J. Herschel, in 1837. He found, however, that the same character was not maintained when the sides began to contract and the spots to diminish: during that process the edges were less strongly defined, being apparently covered by a sort of luminous atmosphere, which often extended so completely across the dark nucleus as to throw a thin thread of light across it, after which the spot soon filled up and disappeared. Capocci concurs with Sir W. Herschel in regarding the internal fringes surrounding the dark nucleus as the section of the inferior stratum of the atmosphere which forms the coating of the sun; he nevertheless thinks that there are indications of solid as well as gaseous luminous matter.

Capocci also observed veins of more intensely luminous matter on the fringes converging towards the nucleus of the spot, which he compares to the structure of the iris surrounding the pupil of the eye.

The drawings of the spots observed by M. Capocci, given in Plate XIV., will illustrate these observations. It is to be regretted, however, that he has not given any measures, either in his memoirs or upon his drawings, by which the position or magnitude of the spots can be determined.

246. **Observations and drawings of Dr. Pastorff, in 1826.** — Dr. Pastorff commenced his course of solar observations as early as 1819. He observed the spots which appeared in 1826, of which he published a series of drawings, from which we have selected those given in Plate XV. from observations made in September and October, contemporaneously with those of M. Capocci. Pastorff gives the position of all, and the dimensions of the principal spots. The numbers on the horizontal and vertical lines express the apparent distances of the spots severally from the limb of the sun in each direction. The actual dimensions may be estimated by observing that 1″ measured at right angles to the visual ray represents 443 miles.

247. **Observations and drawings of Pastorff in 1828.**—In May and June, 1828, a profusion of spots were developed, which were observed and delineated by Pastorff with the most elaborate accuracy.

In Plate XVI., *fig.* 1 represents the positions of the spots as they appeared on the disk of the sun on the 24th of May, at 10 A.M., and *figs.* 2, 3, 4, and 5, represent their forms and magnitudes. The letters A, B, C, D, in *fig.* 1, give the positions of the spots marked by the same letters in *figs.* 2, 3, 4, and 5.

The dimensions of the principal spot of the group A were stupendous; measured in a plane at right angles to the visual line, the length was 44,300 miles, and the breadth 26,580.

The apparent breadth of the black bottom of the spot was 40″, which corresponds to an actual breadth of 17,720 miles. So that the globe of the earth might pass through such a hole, leaving a distance of nearly 5000 miles between its surface and the edges of the chasm.

The superficial dimensions of the several groups of spots observed on the sun on the 24th of May, at 10 A.M., including the shelving sides, were calculated to be as follows: —

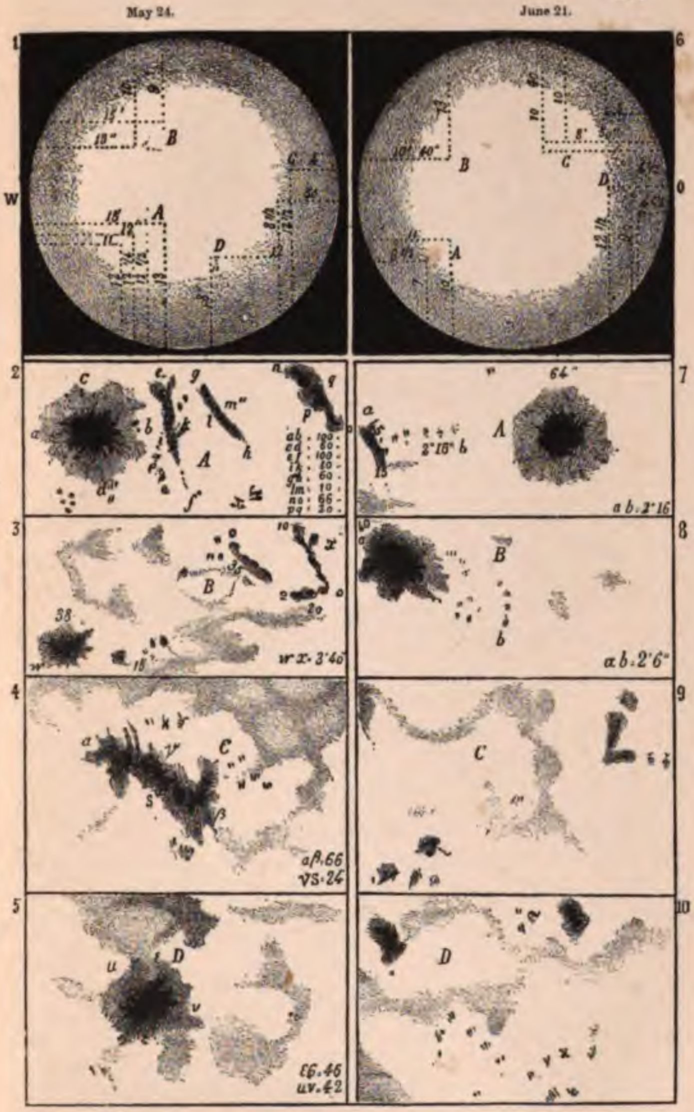
	Square Geog. Miles.
Group A, principal spot	928,000,000
Ditto, smaller spots	736,000,000
Group B	296,000,000
Group C	232,000,000
Group D	304,000,000
Total area	2,496,000,000

Thus it appears that the principal spot of the group A covered a space equal to little less than five times the entire surface of the earth;

SOLAR SPOTS OBSERVED BY PASTORFF, 1826.

1. Oct. 6, 8 h. 15 m. A.M.
2. Oct. 12, 11 h. A.M.
3. Oct. 23, 9 h. 30 m. A.M.
4. Sept. 27, 9 h. A.M.
5. Oct. 2, 8 h. A.M. (1)
6. Oct. 2, 8 h. A.M. (2)

XVI.



SOLAR SPOTS OBSERVED BY PASTORFF, 1828.

and the total area occupied by all the spots collectively amounted to more than twelve times that surface.

On the days succeeding the 24th of May, all the spots were observed to change their form and magnitude from day to day. The great spot of the group A, which even when so close to the limb of the sun as 5′, or a sixth of the apparent diameter, still measured 80″ by 40″, was especially rapid in its variation. Its shelving sides, as well as its dark bottom, were constantly varied, and luminous clouds were seen floating over the latter.

After the disappearance of this large spot, and several of the lesser ones of the other groups, a new spot of considerable magnitude made its appearance on the 13th of June, at the eastern edge of the disk, which gradually increased in magnitude for eight days. On the 21st of June, at half-past 9 in the morning, the disk of the sun exhibited the spots whose position is represented in *fig.* 6, Plate XVI., and whose forms and magnitudes are indicated in *figs.* 7, 8, 9, and 10.

The chief spot of the group A was nearly circular, and measured 64″ in apparent diameter, the diameter of its dark base being about 30″, which, without allowing for projection, represent actual lengths of 28,352 miles, and 13,290 miles, the former being above 3½ times, and the latter nearly 1¾ times the earth's diameter. The process of formation of this spot, surrounded by luminous clouds, was clearly seen. The shelving sides were traversed by luminous ravines or rills, converging towards the centre of the black nucleus, and exhibiting the appearance which Capocci compared to the structure of the iris.

On the same day (21st), another large spot, B, *fig.* 8, appeared, which measured 60″ by 40″.

Pastorff rejects the supposition that these spots were the mere reappearances of those which had been observed on the 24th of May, since they differed essentially in their form, and still more in their *entourage*.

248. **Observations of Sir J. Herschel in 1837.**—Sir J. Herschel, at the Cape of Good Hope, in 1837, observed the spots which at that time appeared upon the sun, and has given various drawings of them in his Cape Observations. These diagrams do not differ in any respect in their general character from those of Capocci and Pastorff. Sir J. Herschel recognised on this occasion the striated or radiated appearance in the fringes already noticed by Capocci and Pastorff. He thinks that this structure is intimately connected with the physical agency by which the spots are produced.

249. **Boundary of fringes distinctly defined.**—It is observed by Sir J. Herschel that one of the most universal and

striking characters of the solar spots is, that the penumbral fringe and black spots are distinctly defined, and do not melt gradually one into the other. The spots are intensely black, and the penumbral fringe of a perfectly uniform degree of shade. In some cases there are two nuances of fringe, one lighter than the other; but in that case no intermixture or gradual fading away of one into the other is apparent. "The idea conveyed," observes Sir J. Herschel, "is more that of the successive withdrawal of veils,—the partial removal of definite films,—than the melting away of a mist or the mutual dilution of gaseous media." This absence of all gradation, this sharply marked suddenness of transition, is, as Sir. J. Herschel also notices, entirely opposed to the idea of the easy miscibility of the luminous, non-luminous, and semi-luminous constituents of the solar envelope.

250. **Observations of M. Schwabe.**—In 1826 M. Schwabe first entered on these researches, which have been continued to the present time. For more than thirty years the sun scarcely appeared above the horizon, without being confronted by M. Schwabe's telescope, and it is found from his results that on an average, observations of the spots were made on 300 separate days in a year. A scrutiny of the sun's disk made so continuously was sure to produce some valuable addition to this branch of astronomical investigation. It has been already mentioned that the number of spots visible at one time is very variable, the surface of the sun being sometimes entirely free and at other times the reverse is shown. Now it appears from M. Schwabe's observations that this variation in the frequency of solar spots, is not accidental, but that they pass through the phases of maximum and minimum in a period of about ten years. This periodicity has since been confirmed by other observers.

It has been long known that the intensity of the magnetic declination is subject to a daily variation, which is supposed to be connected in some way with the sun; but it has also been determined that this daily variation is liable to another variation whose period from minimum to maximum and from maximum to minimum is also about ten years. It is a subject, therefore, of considerable interest to discover whether any connection exists between these two phenomena. Possibly the researches of Mr. Carrington, who has devoted since 1853 much attention to this branch of science, will throw considerable light on the matter.

251. **Solar facules and lucules.**—Independently of the dark spots just described, the luminous part of the solar disk is not uniformly bright. It presents a mottled appearance, which may be compared to that which would be presented by the undulated and agitated surface of an ocean of liquid fire, or to a stratum of lu-

minous clouds of varying depth and having an unequal surface, or the appearance produced by the slow subsidence of some flocculent chemical precipitates in a transparent fluid, when looked at perpendicularly from above. In the space immediately around the edges of the spots extensive spaces are observed, also covered with strongly defined curved or branching streaks, more intensely luminous than the other parts of the disk, among which spots often break out. These several varieties in the intensity of the brightness of the disk have been differently designated by the terms *facules* and *lucules*. These appearances are generally more prevalent and strongly marked near the edges of the disk.

252. **Incandescent coating of the sun gaseous.**—Various attempts have been made to ascertain by the direct test of observation, independently of conjecture or hypothesis, the physical state of the luminous matter which coats the globe of the sun, whether it be solid, liquid, or gaseous.

That it is not solid is admitted to be proved conclusively by its extraordinary mobility, as indicated by the rapid motion of the edges of the spots in closing; and it is contended that a fluid capable of moving at the rate of 42 miles per hour cannot be supposed to be liquid, an elastic fluid alone admitting of such a motion.

253. **Test of this proposed by Arago.**—Arago has, however, suggested a physical test, by which it appears to be proved that this luminous matter must be gaseous; in short, that the sun must be invested with an ocean of flame, since flame is nothing more than aëriform fluid in a state of incandescence (H. 597). This test proposed is based upon the properties of polarised light.

It has been proved that the light emitted from an incandescent body in the liquid or solid state, issuing in directions very oblique to the surface, even when the body emitting it is not smooth or polished, presents evident marks of polarisation, so that such a body, when viewed through a polariscopic telescope, will present two images in complementary colours (O. 285). But, on the other hand, no signs of polarisation are discoverable, however oblique may be the direction in which the rays are emitted, if the luminous matter be flame.

254. **Its result.**—The light proceeding from the disk of the sun has been accordingly submitted to this test. The rays proceeding from its borders evidently issue in a direction as oblique as possible to the surface, and therefore, under the condition most favourable to polarisation, if the luminous matter were liquid. Nevertheless, the borders of the double image produced by the polariscope show no signs whatever of complementary colours, both being equally white even at the very edges.

This test is only applicable to the luminous matter at or near

the edge of the disk, because it is from this only that the rays issue with the necessary obliquity. But since the sun revolves on its axis, every part of its surface comes in succession to the edge of the disk; and thus it follows that the light emanating from every part of it is in its natural or unpolarised state, even when issuing at the greatest obliquity; and, consequently, that the luminous matter is everywhere gaseous.

255. **The sun probably invested with a double gaseous coating.**—All the phenomena which have been here described, and others which our limits compel us to omit, are considered as giving a high degree of physical probability to the hypothesis of Sir W. Herschel already noticed, in which the sun is considered to be a solid, opaque, non-luminous globe invested by two concentric strata of gaseous matter, the first, or that which rests immediately on the surface, being non-luminous, and the other, which floats upon the former, being luminous gas, or flame. The relation and arrangement of these two fluid strata may be illustrated by our own atmosphere, supporting upon it a stratum of clouds. If such clouds were flame, the condition of our atmosphere would represent the two strata on the sun.

The spots in this hypothesis are explained by occasional openings in the luminous stratum, by which parts of the opaque and non-luminous surface of the solid globe are disclosed. These partial openings may be compared to the openings in the clouds of our sky, by which the firmament is rendered partially visible.

The apparent diameter of the sun is not, therefore, the diameter of the solid globe, but that of the globe bounded by the surface of the superior or luminous atmosphere; and this circumstance may throw some light upon the small computed mean density of the sun, since considering the high degree of rarefaction which must be supposed to characterise these atmospheric strata, and especially the superior one, the density of the solid globe will necessarily be much more considerable than the mean density of the volume in which such rarefied matter is included.

256. **A third gaseous atmosphere probable.**—Many circumstances supply indications of the existence of a gaseous atmosphere of great extent above the luminous matter which forms the visible surface of the sun. It is observed that the brightness of the solar disk is sensibly diminished towards its borders. This effect would be produced if it were surrounded by an imperfectly transparent atmosphere, whereas if no such gaseous medium surrounded it, the reverse of such an effect might be expected, since then the thickness of the luminous coating measured in the direction of the visual ray would be increased very rapidly in proceeding from the centre towards the edges. This gradual diminution of brightness in pro-

ceeding towards the borders of the solar disk has been noticed by many astronomers; but it was most clearly manifested in the series of observations made by Sir J. Herschel in 1837, so conclusively, indeed, as to leave no doubt whatever of its reality on the mind of that eminent observer. By projecting the image of the sun's disk on white paper, by means of a good achromatic telescope, this diminution of light towards the borders, was on that occasion rendered so apparent, that it appeared to him surprising that it should ever have been questioned.

257. **Its existence indicated by solar eclipses.**—But the most conclusive proofs of the existence of such an external atmosphere are supplied by certain phenomena observed on the occasion of total eclipses of the sun, which will be fully explained in another chapter of this volume.

258. **Sir J. Herschel's hypothesis to explain the solar spots.**—The immediate cause of the spots being proved to be occasional ruptures of continuity in the ocean of luminous fluid which forms the visible surface of the solar globe, it remains to discover what physical agency can be imagined to produce dynamical phenomena on a scale so vast as that which the changes of appearance of the spots indicate.

The regions of the spots being two zones parallel to the solar equator, manifests a connection between these phenomena and the sun's rotation. The like regions on the earth are the theatres of the trade-winds and anti-trades, and of hurricanes, tornadoes, waterspouts, and other violent atmospheric disturbances. On the planets the same regions are marked by belts, appearances which are traced by analogy to the same physical causes as those which produce the trades and other atmospheric perturbations prevailing in the tropical and ultra-tropical zones. Analogy, therefore, suggests the inquiry, whether any physical agencies can exist upon the sun similar to those which produce these phenomena on the earth and planets.

So far as relates to the earth it is certain, and so far as relates to the planets probable, that the immediate physical cause of these phenomena is the inequality of the exposure of the earth's surface to solar radiation, and the consequent inequality of temperature produced in different atmospheric zones, either by the direct or reflected calorific rays of the sun, combined with the earth's rotation (233). But since the sun is itself the common fountain of heat, supplying to all, and receiving from none, no similar agency can prevail upon it. It remains, therefore, to consider whether the play of the physical principles which are in operation on the sun itself, irrespective of any other bodies of the system, can supply an explanation of such a local difference of temperature as, combined

with the sun's rotation, would produce any special physical effects on the macular zones, by which the phenomena of the spots might be explicable.

The heat generated by some undiscovered agency upon the sun is dispersed through the surrounding space by radiation. If, as may be assumed, the rate at which this heat is generated be the same on all parts of the sun, and if, moreover, the radiation be equally free and unobstructed from all parts of its surface, it is evident that an uniform temperature must be everywhere maintained. But if, from any local cause, the radiation be more obstructed in some regions than in others, heat will accumulate in the former, and the local temperature will be more elevated there than where the radiation is more free.

But the only obstruction to free radiation from the sun must arise from the atmosphere with which, to a height so enormous, it is surrounded. If, however, this atmosphere have everywhere the same height and the same density, it will present the same obstruction to radiation, and the effective radiation which takes place through it, though more feeble than that which would be produced in its absence, is still uniform.

But since the sun has a motion of rotation on its axis in $25^d\ 7^h\ 48^m$, its atmosphere, like that of the earth, must participate in that motion and the effects of centrifugal force upon matter so mobile: the equatorial zone being carried round with a velocity greater than 300 miles per second, while the polar zones are moved at a rate indefinitely slower, all the effects to which the spheroidal form of the earth is due will affect this fluid with an energy proportionate to its tenuity and mobility, the consequence of which will be that it will assume the form of an oblate spheroid, whose axis will be that of the sun's rotation. It will flow from the poles to the equator, and its height over the zones contiguous to the equator will be greater than over those contiguous to the poles, in a degree proportionate to the ellipticity of the atmospheric spheroid.

Now, if this reasoning be admitted, it will follow that the obstruction to radiation produced by the solar atmosphere is greatest over the equator, and gradually decreases in proceeding towards either pole. The accumulation of heat, and consequent elevation of temperature, is, therefore, greatest at the equator, and gradually decreases towards the poles, exactly as happens on the earth from other and different physical causes.

The effects of this inequality of temperature, combined with the rotation, upon the solar atmosphere, will of course be similar in their general character, and different only in degree from the phenomena produced by the like cause on the earth. Inferior currents

will, as upon the earth, prevail towards the equator, and superior counter-currents towards the poles (233). The spots of the sun would, therefore, be assimilated to those tropical regions of the earth in which, for the moment, hurricanes and tornadoes prevail, the upper stratum which has come from the equator being temporarily carried downwards, displacing by its force the strata of luminous matter beneath it (which may be conceived as forming an habitually tranquil limit between the opposite upper and under currents), the upper of course to a greater extent than the lower, and thus wholly or partially denuding the opaque surface of the sun below. Such processes cannot be unaccompanied by vorticose motions, which, left to themselves, die away by degrees, and dissipate, with this peculiarity, that their lower portions come to rest more speedily than their upper, by reason of the greater distance below, as well as the remoteness from the point of action, which lies in a higher region, so that their centre (as seen in our waterspouts, which are nothing but small tornadoes) appears to retreat upwards.*

Sir J. Herschel maintains that all this agrees perfectly with what is observed during the obliteration of the solar spots, which appear as if filled in by the collapse of their sides, the penumbra closing in upon the spot and disappearing afterwards.

It would have rendered this ingenious hypothesis still more satisfactory, if Sir J. Herschel had assigned a reason why the luminous and subjacent non-luminous atmosphere, both of which are assumed to be gaseous fluids, do not affect, in consequence of the rotation, the same spheroidal form which he ascribes to the superior solar atmosphere.

259. **Calorific power of solar rays.** — The intensity of heat on the sun's surface has been found to be seven times as great as that of the vivid ignition of the fuel in the strongest blast furnace. This power of solar light is also proved by the facility with which the calorific rays pass through glass. Herschel found, by experiments made with an actinometer, that 81·6 per cent. of the calorific rays of the sun penetrate a sheet of plate glass 0·12 inch thick, and that 85·9 per cent. of the rays which have passed through one such plate will pass through another.†

260. **Probable physical cause of solar heat.** — One of the most difficult questions connected with the physical condition of the sun, is the discovery of the agency to which its heat is due. To the hypothesis of combustion, or any other which involves the supposition of extensive chemical change in the constituents of the surface, there are insuperable difficulties. Conjecture is all

* Herschel's *Cape Observations*, p. 434.

† Ibid. p. 133.

that can be offered, in the absence of all data upon which reasoning can be based. Without any chemical change, heat may be indefinitely generated either by friction or by electric currents, and each of these causes have accordingly been suggested as a possible source of solar heat and light. According to the latter hypothesis, the sun would be a great ELECTRIC LIGHT in the centre of the system.

CHAPTER XIII.

THE SOLAR SYSTEM.

261. **Perception of the motion and position of surrounding objects depends upon the station of the observer.** — The facility, clearness, and certainty with which the motions, distances, magnitudes, and relative position and arrangement of any surrounding objects can be ascertained, depends in a great degree, upon the station of the observer. The form and relative disposition of the building, streets, squares, and limits of a great city, are perceived, for example, with more clearness and certainty if the station of the observer be selected at the summit of a lofty building, than if it were at any station level with the general plane of the city itself. This advantage attending an elevated place of observation is much augmented if the objects observed are affected by various and complicated motions *inter se*. A general, who directs the evolutions of a battle, seeks an elevated position from which he can obtain, as far as it is practicable to do so, a *bird's eye* view of the field; and it was at one time proposed to employ captive balloons by which observers could be raised to a sufficient elevation above the plane of the military manœuvres.

All these difficulties, which arise from the station of the observer being in the general plane of the motions observed, are, however, infinitely aggravated when the station has itself motions of which the observer is unconscious; in such case, the effects of these motions are optically transferred to surrounding objects, giving them apparent motions in directions contrary to that of the observer, and apparent velocities, which vary with their distance from the observer, increasing as that distance diminishes, and diminishing as that distance increases.

All such effects are imputed by the unconscious observer to so many real motions in the objects observed; and, being mixed up with the motions by which such objects themselves are actually

affected, an inextricable confusion of changes of position, apparent and real, results, which involves the observer in obscurity and difficulty, if his purpose be to ascertain the actual motions and relative distances and arrangement of the objects around him.

262. **Peculiar difficulties presented by the solar system.**—All these difficulties are presented in their most aggravated form to the observer, who, being placed upon the earth, desires to ascertain the motions and positions of the bodies composing the solar system. These bodies all move nearly in one plane, and from that plane the observer never departs: he is, therefore, deprived altogether of the facilities and advantages which a bird's eye view of the system would afford. He is like the commander who can find no station from which to view the evolutions of the army against which he has to contend, except one upon a dead level with it, but with this great addition to his embarrassment, that his own station is itself subject to various changes of position, of which he is altogether unconscious, and which he can only ascertain by the apparent changes of position which they produce among the objects of his observation and inquiry.

The difficulties arising out of these circumstances obstructed for ages the progress of astronomical science. The persuasion so universally entertained of the absolute immobility of the earth, was not only a vast error itself, but the cause of numerous other errors. It misled inquirers by compelling them to ascribe motions to bodies which are stationary, and to ascribe to bodies not stationary, motions altogether different from those with which they are really affected.

263. **General arrangement of bodies composing the solar system.**—The solar system is an assemblage of great bodies, globular in their form, and analogous in many respects to the earth. Like the earth, they revolve round the sun as a common centre, in orbits which do not differ much from circles: all these orbits are very nearly, though not exactly, in the same plane with the annual orbit of the earth, and the orbital motions all take place in the same direction as that of the earth.

Several of these bodies are the centres of secondary systems, another order of smaller globes revolving round them respectively in the same manner, and according to the same dynamical laws as govern their own motion round the sun.

264. **Planets primary and secondary.**—This assemblage of globes which thus revolve round the sun as a common centre, of which the earth itself is one, are called PLANETS; and the secondary globes, which revolve round several of them, are called SECONDARY PLANETS, SATELLITES, or MOONS, one of them being our

moon, which revolves round the earth as the earth itself revolves round the sun.

265. **Primary carry with them the secondary round the sun.**—The primary planets which are thus attended by satellites, carry the satellites with them in their orbital course; the common orbital motion, thus shared by the primary planet with its secondaries, not preventing the harmonious motion of the secondaries round the primary as a common centre.

266. **Planetary motions to be first regarded as circular, uniform, and in a common plane.**—It will be conducive to the more easy and clear comprehension of the phenomena to consider, in the first instance, the planets as moving round the sun as their common centre in exactly the same plane, in exactly circular orbits, and with motions exactly uniform. None of these suppositions correspond precisely with their actual motions; but they represent them so very nearly, that nothing short of very precise means of observation and measurement is capable of detecting their departure from them. The motions of the system thus understood will form a first and very close approximation to the truth. The modifications to which the conclusions thus established must be submitted, so as to allow for the departures of the several planets from the plane of the ecliptic, of their orbits from exact circles, and of their motions from perfect uniformity, will be easily introduced and comprehended. But even these will supply only a second approximation. Further investigation will show series after series of corrections, more and more minute in their quantities, and requiring longer and longer periods of time to manifest the effects to which they are directed.

267. **Inferior and superior planets.**—The concentric orbits of the planets then are included one within another, augmenting successively in their distances from the centre, so as in general to leave a great space between orbit and orbit.

Those planets which are included within the orbit of the earth are called INFERIOR PLANETS, and all the others are called SUPERIOR PLANETS.

268. **Periods.**—The PERIODIC TIME of a planet is the interval between two successive returns to the same point of its orbit, or, in short, the time it takes to make a complete revolution round the sun. It is found by observation, as might be naturally expected, that the periodic time increases with the orbit, being much longer for the more distant planets; but, as will appear hereafter, this increase of the periodic time is not in the same proportion as the increase of the orbit.

269. **Synodic motion.**—The motion of a planet considered merely in relation to that of the earth, without reference to its actual position in its orbit, is called its SYNODIC MOTION.

270. **Geocentric and heliocentric motions.**—The position and motion of a planet as they appear to an observer on the earth are called GEOCENTRIC*; and as they would appear if the observer were transferred to the sun, are called HELIOCENTRIC.

271. **Heliocentric motion deducible from geocentric.**—Although the apparent motions cannot be directly observed from the sun as a station, it is a simple problem of elementary geometry to deduce them from the geocentric motions, combined with the relative distances of the earth and planet from the sun; so that we are in a condition to state with perfect clearness, precision, and certainty, all the phenomena which the motions of the planetary system would present, if, instead of being seen from the movable station of the earth, they were witnessed from the fixed central station of the sun.

272. **Elongation.**—The geocentric position of a planet in relation to the sun, or the angle formed by lines drawn from the earth to the sun and planet, is called the ELONGATION of the planet, and is EAST or WEST, according as the planet is at the one side or the other of the sun.

273. **Conjunction.**—When the elongation of a planet is nothing, it is said to be in CONJUNCTION, being then in the same direction as the sun when seen from the earth.

274. **Opposition.**—When the elongation of a planet is 180°, it is said to be in OPPOSITION, being then in the quarter of the heavens directly opposite to the sun.

It is evident that a planet which is in conjunction, passes the meridian at or very near noon, and is therefore above the horizon during the day, and below it during the night.

On the other hand, a planet which is in opposition, passes the meridian at or very near midnight, and therefore is above the horizon during the night, and below it during the day.

275. **Quadrature.**—A planet is said to be in quadrature when its elongation is 90°.

In this position it passes the meridian at about six o'clock in the morning, when it has western quadrature, and six o'clock in the evening, when it has eastern quadrature. It is, therefore, above the horizon on the eastern side of the firmament during the latter part of the night in the former case, and on the western side during the first part of the night in the latter case. It is a morning star in the one case, and an evening star in the other.

276. **Synodic period.**—The interval which elapses between two similar elongations of a planet is called the SYNODIC PERIOD of

* From the Greek words γῆ (gē) and ἥλιος (helios), signifying *the earth* and *the sun*.

the planet. Thus, the interval between two successive oppositions or two successive eastern or western quadratures, is the synodic period.

277. **Inferior and superior conjunction.**—A superior planet can never be in conjunction except when it is placed on the side of the sun opposite to the earth, so that a line drawn from the earth through the sun would, if continued beyond the sun, be directed to the planet. An inferior planet is, however, also in conjunction when it crosses the line drawn from the earth to the sun, between the earth and sun. The former is distinguished as SUPERIOR and the latter as INFERIOR conjunction.

As inferior conjunction necessarily supposes the planet to be nearer to the sun than the earth, and opposition supposes it to be more distant, it follows that inferior planets alone can be in inferior conjunction, and superior planets alone in opposition.

278. **Direct and retrograde motion.**—When a planet appears to move in the direction in which the sun appears to move, its apparent motion is said to be DIRECT; and when it appears to move in the contrary direction, it is said to be RETROGRADE.

The apparent motion of an inferior planet is always direct, except within a certain elongation east and west of inferior conjunction, when it is retrograde.

279. **Conditions under which a planet is visible in the absence of the sun.**—It is evident that to be visible in the absence of the sun, a celestial object must be so far elongated from that luminary as to be above the horizon before the commencement of the morning twilight, or after the end of the evening twilight. One or two of the planets have, nevertheless, an apparent magnitude so considerable, and a lustre so intense, that they are sometimes seen with the naked eye, even before sunset or after sunrise, and may, in general, be seen with a telescope when the sun has a considerable altitude. In most cases, however, to be visible without a telescope, a planet must have an elongation greater than 30° to 35°.

As an instance of the visibility of a planet to the naked eye during the day time, it may be mentioned that Venus has frequently been seen at Greenwich, between one and two o'clock in the afternoon, when the planet was near the meridian, and under favourable circumstances with a brilliant sky.

280. **Evening and morning star.**—Since the inferior planets can never attain so great an elongation as 90°, they must always pass the meridian at an interval considerably less than six hours before or after the sun. If they have eastern elongation they pass the meridian in the afternoon, and are visible above the horizon after sunset, and are then called EVENING STARS. If they have

western elongation they pass the meridian in the forenoon, and are visible above the eastern horizon before sunrise, and are then called MORNING STARS.

281. **Appearance of superior planets at various elongations.**—A superior planet, having every degree of elongation east and west of the sun from 0° to 180°, passes the meridian during its synodic period at all hours of the day and night. Between conjunction and quadrature, its elongation east or west of the sun being less than 90°, it passes the meridian earlier than six o'clock in the afternoon in the former case, and later than six o'clock in the forenoon in the latter case, being, like an inferior planet, an evening star in the former, and a morning star in the latter case.

At eastern quadrature it passes the meridian at six in the evening, and at western quadrature at six in the morning, appearing still as an evening star in the former, and as a morning star in the latter case.

Between the eastern quadrature and opposition, the elongation being more than 90° east of the sun, the planet must pass the meridian between six o'clock in the evening and midnight, and is therefore visible from sunset until some hours before sunrise. Between western quadrature and opposition, the elongation being more than 90° west of the sun, the planet must pass the meridian at some time between midnight and six o'clock in the morning, and it is therefore visible from some hours after sunset until sunrise.

At opposition the planet passes the meridian at midnight, and is therefore visible from sunset to sunrise.

282. **Phases of a planet.**—While a planet revolves, that hemisphere which is presented to the sun is illuminated, and the other dark. But since the same hemisphere is not presented generally to the earth, it follows that the visible hemisphere of the planet will consist of a part of the dark and a part of the enlightened hemisphere, and, consequently, the planet will exhibit PHASES, the varieties and limits of which will depend upon the relative directions of the lines drawn from the earth and sun to the planet. It is evident that the section of the planet at right angles to a line drawn from the sun to its centre is the base of its enlightened hemisphere, while the section at right angles to a line drawn from the earth to its centre, is the base of its visible hemisphere. The less the angle included between these lines is, the greater will be the portion of the visible hemisphere which is enlightened.

283. **Perihelion, aphelion, mean distance.**—That point of the elliptic orbit at which a planet is nearest to the sun is called PERIHELION, and that point at which it is most remote is called APHELION.

The MEAN DISTANCE of a planet from the sun is half the sum of its greatest and least distances.

284. **Major and minor axes, and excentricity of the orbit.**—The *fig.* 54 represents an ellipse, of which F is the focus and C the centre. The line C F continued to P and A is the MAJOR AXIS, sometimes called the transverse axis. Of all the diameters which can be drawn through the centre C, terminating in the curve, it is the longest, while M C M′, drawn at right angles to it, called the MINOR AXIS, is the shortest. The line F M′, which is equal to P C, half the major axis, and therefore to half the sum of the greatest and least distances of the ellipse from its focus, is the MEAN DISTANCE.

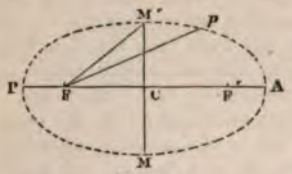


Fig. 54.

A planet, is, therefore, at its mean distance from the sun when it is at the extremities of the minor axis of its orbit.

There is another point F′ on the major axis, at a distance F′ C from the centre, equal to F C, which has also the geometric properties of the focus. It is sometimes distinguished as the EMPTY FOCUS of the planet's orbit.

Ellipses may be more or less EXCENTRIC, that is to say more or less oval. The less excentric they are, the less they differ in form from a circle. The degree in which they have the oval form, depends on the ratio which the distance F C of the focus from the centre, bears to P C, the semi-axis major. Two ellipses of different magnitudes in which this ratio is the same, have a like form, and are equally excentric. The less the ratio of C F to C P is, the more nearly does the ellipse resemble a circle. This ratio, is, therefore, called the EXCENTRICITY.

The excentricity of a planet's orbit will, therefore, be that number which expresses the distance of the sun from the centre of the ellipse, the semi-axis major of the orbit being taken as the unit.

285. **Apsides, anomaly.**—The points of PERIHELION and APHELION are called by the common name of APSIDES.

If an eye placed at the sun F look in the direction of P, that point will be projected upon a certain point on the firmament. This is called the PLACE OF PERIHELION.

The angle formed by a line drawn from the sun to the place *p* of a planet, and the major axis of its orbit, or, what is the same, the angular distance of the planet from its perihelion, as seen from the sun, is called its ANOMALY.

If an imaginary planet be supposed to move from perihelion to aphelion, with any uniform angular motion round the sun in the

same time that the real planet moves between the same points with a variable angular motion, the anomaly of this imaginary planet is called the MEAN ANOMALY of the planet.

286. **Place of perihelion.**—The PLACE OF PERIHELION is expressed by indicating the particular fixed star at or near which the planet at P is seen from F, or, what is the same, the distance of that point from some fixed and known point in the heavens. The point selected for this purpose is the vernal equinoxial point, or the *first point of Aries*. The distance of perihelion from this point, as seen from the sun, is called the LONGITUDE OF PERIHELION, and is an important condition affecting the position of the planet's orbit in space.

287. **Excentricities of orbits small.**—The planets' orbits, like that of the earth, though elliptical, are very slightly so. The excentricities are so minute, that if the form of the orbit were delineated on paper, it could not be distinguished from a circle except by very exactly measuring its breadth in different directions.

288. **Law of attraction deduced from elliptic orbit.**—As the equable description of areas round the centre of the sun proves that point to be the centre of attraction, the elliptic form of the orbit and the position of the sun in the focus indicate the LAW according to which this attraction varies as the distance of the planet from the sun varies. Newton has demonstrated, in his PRINCIPIA, that such a motion necessarily involves the condition that the intensity of the attractive force, at different points of the orbit, varies inversely as the square of the distance, increasing as the square of the distance decreases, and *vice versâ*.

289. **The orbit might be a parabola or hyperbola.**—Newton also proved that the converse is not necessarily true, and that a body may move in an orbit which is not elliptical round a centre of force which varies according to this law. But he showed that the orbit, if not an ellipse, must be one or other of two curves, a PARABOLA or HYPERBOLA, having a close geometric relation to the ellipse, and that in all cases the centre of force would be the focus of the curve.

These three sorts of curves, the ellipse, the parabola, and hyperbola, are those which would be produced by cutting a cone in different directions by a plane, and they are hence called the CONIC SECTIONS.

290. **Conditions which determine the species of the orbit.**—The conditions under which the orbit of a planet might be a parabola or hyperbola, depend on the relation which the velocity of the motion of the planet, at any given point of the orbit, bears to the intensity of the attractive force at that point. It is demon-

strable that, if the velocity with which a planet moves at any given point of its orbit were suddenly augmented in a certain proportion, its orbit would become a parabola, and if it were still more augmented, it would become an hyperbola.

The ellipse is a curve which, like the circle, *returns into itself*, so that a body moving in it must necessarily retrace the same path in an endless succession of revolutions. This is not the character of the parabola or hyperbola. They are not closed curves, but consist of two branches which continue to diverge from each other without ever meeting. A planet, therefore, which would thus move, would pass near the sun once, following a curved path, but would then depart never to return.

291. **Law of gravitation general.**—The elliptic form of the orbit of a planet indicates the law which governs the variation of the sun's attraction from point to point of such orbit; but beyond this orbit it proves nothing. It remains, therefore, to show from the planetary motions round the sun, and from the motions of the satellites round their primaries, that the same law of attraction by which the intensity decreases as the square of the distance from the centre of attraction increases, and *vice versâ*, is universal.

The attraction exerted upon any body may be measured, in general, as that of the earth on bodies near its surface is measured, by the spaces through which the attracted body would be drawn in a given time. It has been found, that the attraction which the earth exerts at its surface, is such as to draw a body towards it through 193 inches in a second. Now if the space through which the sun would, by its attraction at any proposed distance, draw a body in one second, could be found, the attraction of the sun at that distance could be exactly compared with, and measured by the attraction of the earth, just as the length of any line or distance is ascertained, by applying to it, and comparing it with, a standard yard measure.

292. **Inclination of the orbits — nodes.**—For the sake of illustration, we will suppose the planets to be moving in the plane of the earth's orbit. If this were strictly true, no planet would ever be seen on the heavens out of the ecliptic. The inferior planets, when in inferior conjunction, would *always* appear as spots on the sun; and when in superior conjunction, they, as well as the superior planets, would *always* be behind the sun's disk. This is not the case. The planets generally, superior and inferior, are seldom seen actually upon the ecliptic, although they are never far removed from it. The centre of the planet, twice in each revolution, is observed upon the ecliptic. The points at which it is thus found upon the plane of the earth's orbit are at opposite sides of the sun, 180° asunder, as seen from that luminary. At one of them the

planet passes from the south to the north of the ecliptic, and at the other from the north to the south.

293. **Nodes, ascending and descending.**—Those points, where the centre of a planet crosses the ecliptic, are called its NODES, that at which it passes from south to north being called the ASCENDING NODE, and the other the DESCENDING NODE.

While the planet passes from the ascending to the descending node, it is north of the ecliptic; and while it passes from the descending to the ascending node, it is south of it.

All these phenomena indicate that the planet does not move in the plane of the ecliptic but in a plane inclined to it at a certain angle. This angle cannot be great, since the planet is never observed to depart far from the ecliptic. With a few exceptions which will be noticed hereafter, the obliquity of the planets' orbits do not amount to more than 7°.

294. **The zodiac.**—Most of the planets, therefore, not departing more than about 8° from the ecliptic, north or south, their motions are limited to a zone of the heavens bounded by two parallels to the ecliptic at this distance, north and south of it.

295. **To determine the real diameters and volumes of the bodies of the system.**—The apparent diameter of a planet at a known distance being observed, the real diameter may be computed by multiplying the linear value of 1″ at the distance of the object, by its apparent diameter expressed in seconds of space.

The disks of the inferior planets not being visible at inferior conjunction when their dark hemispheres are presented to the earth, and being lost in the effulgence of the sun at superior conjunction, can only be observed between their greatest elongation and superior conjunction, when they appear gibbous. The distance of the planet from the earth is computed in this position by knowing the distances of the planet and the earth from the sun, and the angle under the lines drawn from the sun to the earth and planet, which can always be computed. This distance being obtained, the linear value of 1″ at the planet being multiplied by the greatest breadth of its gibbous disk, the real diameter will be obtained.

Observations of Venus are, however, occasionally made very near to superior conjunction, the disk of the planet being at the time apparently circular, but of limited magnitude, owing to the comparatively great distance of the planet from the earth.

In the case of the superior planets, their diameters may be best obtained when in opposition, because then they appear with a full disk, and, being nearer to the earth than at any other elongation, have the greatest possible magnitude. Their distance from the earth in this position, is always the difference between the distances of the earth and planet from the sun.

When the real diameters are found, the volumes can be obtained, since they are as the cubes of the real diameters.

296. **Methods of determining the masses of the bodies of the solar system.**—The work of the astronomer is but imperfectly performed when he has only mentioned the distances and magnitudes, and ascertained the motions and velocities, of the great bodies of the universe. He must not only measure, but weigh these stupendous masses.

The masses or quantities of matter in bodies upon the surface of the earth are estimated and compared by their weights—that is, by the intensity of the attraction which the earth exerts upon them. It is inferred that equal quantities of matter at equal distances from the centre of the earth are attracted by equal forces, inasmuch as all masses, great and small, fall with the same velocity (M. 231).

The intensity of the attraction with which the earth thus acts upon a body at any given distance from its centre depends on the mass or quantity of matter composing the earth. If the mass of the earth were suddenly increased in any proposed ratio, the weights of all bodies on its surface, or at any given distance from its centre, would be increased in the same ratio, and in like manner, if its mass were diminished, the weights would be decreased in the same ratio. In short, the weights of bodies at any given distance from the earth's centre would vary with, and be exactly proportional to, every variation in the mass of the earth.

A further explanation of the method of determining the masses of the different bodies of the solar system, will be found in the concluding chapter of this volume.

297. **To determine the masses of planets which have no satellites.**—The masses of the bodies composing the solar system are measured, and compared one with another, by ascertaining, with the necessary precision, any similar effects of their attractions, and allowing for the effects of the difference of distances. The effects which are thus taken to measure the masses, and to exhibit their ratio to the mass of the sun in the case of planets attended by satellites, is the space through which a satellite would be drawn by its primary, and the space through which a planet would be drawn in the same time by the sun. These spaces indicate the actual forces of attraction of the planet upon the satellite and of the sun upon the planet, and when the effect of the difference of distance is allowed for, the ratio of the mass of the planet to the mass of the sun is found.

In the case of planets not attended by satellites, the effect of their gravitation is not manifested in this way, and there is no body smaller than themselves, and sufficiently near them to exhibit the same easily measured and very sensible effects of their attrac-

tion, and hence there is considerable difficulty, and some uncertainty as to their exact masses.

298. **Mass of Mars estimated by its attraction upon the earth.**—The nearest body of the system to which Mars approaches is the earth, its distance from which in opposition is nearly fifty millions of miles, or half the distance of the earth from the sun. Now, since the volume of Mars is only the sixth part of that of the earth, it may be presumed that, whatever be its density, its mass must be so small that the effect of its attraction on the earth at a distance so great must be very minute, and therefore difficult to ascertain by observation. Nevertheless, small as the effect thus produced is, it is not imperceptible, and a certain deviation from the path it would follow, if the mass of Mars were not thus present, has been observed. To infer from this deviation the mass of Mars is, however, a problem of much greater complexity than the determination of the mass of a planet by observing its attraction upon its satellite. The method adopted for the solution of the problem is a sort of "trial and error." A conjectural mass is first imputed to Mars, and the deviation from its course which such a mass would cause in the orbital motion of the earth is computed. If such deviation is greater or less than the actual deviation observed, another conjectural mass, greater or less than the former, is imputed to the planet, and another computation made of the consequent deviation, which will come nearer to the true deviation than the former. By repeating this approximative and tentative process a mass is at length found, which, being imputed to Mars, would produce the observed deviation; and this is accordingly assumed to be the true mass of the planet.

In this way the mass of Mars has been approximatively estimated to be about the eighth part of the mass of the earth.

The smallness of this mass compared with its distance from the only body on which it can exert a sensible attraction will explain the difficulty of ascertaining it, and the uncertainty which attends its value.

299. **Masses of Venus and Mercury.**—The same causes of difficulty and uncertainty do not affect in so great a degree the planet Venus, whose mass is somewhat less than that of the earth, and which moreover comes when in inferior conjunction within about thirty millions of miles of the earth. The effects of the attraction of the mass of this planet, upon the earth's orbital motion are therefore much more decided. The deviation produced by it, is not only easily observed and measured, but it affects in a sensible manner the position of the plane of the earth's orbit. By the same system of "trial and error," the mass of this planet is ascertained to be an eighth less than that of the earth.

The difficulties attending the determination of the mass of Mercury are still greater than those which affect Mars, and its true value is still very uncertain. Attempts have lately been made to approximate to its value, by observing the effects of its attraction on one of the comets.

300. **Methods of determining the mass of the moon.**—Owing to its proximity and close relation to the earth, and the many and striking phenomena connected with it, the determination of the mass of the moon becomes a problem of considerable importtance. There are various observable effects of its attraction by which the ratio of its mass to those of the sun or earth may be computed.

301. 1st. **By nutation.**—It has been shown that the attractions of the masses of the sun and moon upon the protuberant matter surrounding the equator of the terrestrial spheroid produce a regular and periodic change in the direction of the axis of the earth, and consequently a corresponding change in the apparent place of the celestial pole. The share which each mass has in these effects being ascertained, their relative attractions exerted upon the redundant matter at the terrestrial equator is found, and the effect of the difference of distance being allowed for, the ratio of the attracting masses is obtained.

302. 2ndly. **By the tides.**—It has also been shown that, by the attractions of the masses of the sun and moon, the tides of the ocean are produced. The share which each mass has in the production of these effects being ascertained, and the effect of the difference of distance being allowed for, the ratio of the masses of the sun and moon is obtained.

303. 3rdly. **By the common centre of gravity of the moon and the earth.**—It has been stated that the centre of attraction round which the moon moves in her monthly course is the centre of the earth. This is nearly, but not exactly true. By the law of gravitation the centre of attraction is not the centre of the earth, but the centre of gravity of the earth and moon, that is, a point whose distance from the centre of the earth has to its distance from the centre of the moon the same ratio as the mass of the moon has to the mass of the earth. (M. 309.) Around this point, which is within the surface of the earth, both the earth and moon revolve in a month, the point in question being always between their centres. If, then, the position of this point can be found, the ratio of its distances from the centres of the earth and moon will give the ratio of their masses.

Now, the monthly motion of the earth round such a centre would necessarily produce a corresponding apparent monthly displacement of the sun. Such displacement, though small (not

amounting to more than a few seconds), is nevertheless capable of observation and measurement. The exact place of the sun's centre being therefore computed on the supposition of the absence of the moon, and compared with its observed place, the motion of the earth's centre and the position of the point round which it revolves has been determined, and the relative masses of the earth and moon thus found.

304. 4thly. **By terrestrial gravity.**—By what has been already explained, the space through which the moon would be drawn towards the earth in a given time by the earth's attraction can be determined. Let this space be expressed by s. The linear velocity v of the moon in its orbit can also be determined. Now, if r be the radius of the orbit, we shall have $r = \frac{v^2}{2s}$.

We find, therefore, the radius vector of the moon's orbit by dividing the square of its linear velocity by twice the space through which it would fall towards the earth in the unit of time. But this radius vector is the distance of the moon's centre from the common centre of gravity of the earth and moon. The distance of that point, therefore, from the centre of the earth, and consequently the ratio of the masses of the earth and moon, will be thus found.

All these methods give results in very near accordance, from which it is inferred that the mass of the moon is not less than the seventy-fifth, nor greater than the ninetieth part of the mass of the earth, but from the most trustworthy determinations it is considered to be about the eightieth part of the earth's mass.

305. **To determine the masses of the satellites.**—The same difficulties which attend the determination of the masses of the planets not accompanied by satellites, also attend the determination of the masses of satellites themselves, and the same methods are applicable to the solution of the problem. The masses of the satellites of Jupiter and the other superior planets are ascertained in relation to those of their primaries by the disturbing effects which they produce upon the motions of each other.

306. **Classification of the planets in three groups—First group—the terrestrial planets.**—Of the planets hitherto discovered, three which present in several respects remarkable analogies to the earth, and whose orbits are included within a circle which exceeds the earth's distance from the sun by no more than one-half, have been from these circumstances denominated TERRESTRIAL PLANETS. Two of these, MERCURY and VENUS, revolve within the orbit of the earth; and the third, MARS, revolves in an orbit outside that of the earth, its distance from the earth when in opposition being only half the earth's distance from the sun. A

supposed new planet, which has received the name of VULCAN, and whose orbit is included within that of Mercury, must be added to this group.

307. **Second group — the planetoids.** — A chasm having a width measuring little less than four times the earth's distance, separated, for many ages after astronomy had made considerable progress, the terrestrial planets from the more remote members of the system. The labours of observers since the beginning of the present century, but chiefly since 1845, have filled this chasm with no less than ninety-one planets, distinguished from all the other bodies of the system by their extremely minute magnitudes, and by the circumstance of revolving in orbits very nearly equal. These bodies have been distinguished by the name of ASTEROIDS or PLANETOIDS, the latter being preferable as the most characteristic and appropriate.

308. **Third group — the major planets.** — Outside the planetoids, and at enormous distances from the sun and from each other, revolve four planets of stupendous magnitude — named JUPITER, SATURN, URANUS, and NEPTUNE: the two former being visible to the naked eye, were known to the ancients; the two latter are telescopic, and were discovered in modern times.

CHAPTER XIV.

THE TERRESTRIAL PLANETS.

I. VULCAN.

309. **The supposed new inferior planet.** — The supposed new inferior planet, which has received the name of VULCAN, is believed by many, from sufficient proofs having been given by the discoverer, to be in reality a member of the solar system. Some degree of doubt, however, will necessarily be attached to the existence of this planet, until its identity be established by further observations.

It will be sufficient therefore here to state that on the 26th of March, 1859, a small dark body was seen to pass over a portion of the sun's disk by M. Lescarbault, a physician at Orgères in the department Eure et Loire, France, having every appearance of being a planet, whose orbit would be included within that of Mercury. From his observations, which were registered in a very careful, though homely, manner, as well as from his replies to a very severe

cross-examination by M. Le Verrier, who had undertaken to prove the truthfulness of the discovery, that astronomer was convinced that he ought not to doubt the reality of the observation, or the good faith of the observer.

From the observations of M. Lescarbault, it is supposed that the distance of Vulcan from the sun is about fourteen millions of miles; its period less than 20 days; the inclination of its orbit 12 or 13 degrees; and the longitude of the ascending node 13 degrees.

This suspected planet has been systematically looked for at several of the principal observatories, at those times when its orbit would have been projected on the sun's disk. The search, however, has not been successful. M. Liais, an observer of considerable practice, who happened to be engaged in the observation of solar phenomena, at Rio Janeiro, at the identical moment of M. Lescarbault's alleged discovery, feels certain that no object of a planetary nature was visible at that particular time. It is now considered by most practical astronomers that the existence of this supposed object is, to say the least, very doubtful.

II. Mercury.

310. **Period.**—If we except Vulcan, Mercury is the nearest of the planets to the sun, and that which completes its revolution in the shortest interval of time.

The synodic period of this planet, determined by immediate observation, is 115·88 days. Its mean sidereal period is 87·97 days.

If the earth's period be expressed by 1, that of Mercury will therefore be 0·2408.

311. **Mean and extreme distances from the sun and earth.**—The excentricity of the orbit of Mercury is much more considerable than those of the planets generally, being a little more than 0·2056, expressed in parts of the mean distance. The distance of the planet from the sun is, therefore, subject to a variation, amounting to so much as a fifth part of its mean value, its mean distance being about 35¼ millions of miles. The greatest and least distances from the sun are, therefore,

42½ millions of miles in aphelion
28 " " perihelion.

The distance is, therefore, subject to a variation in the ratio of 5 to 7 very nearly.

The mean distances of the planet from the earth are, therefore,

56 millions of miles at inferior conjunction
126¾ " " superior conjunction.

These distances are subject to an increase and diminution of seven and one-third millions of miles due to the excentricity of the

orbit of the planet, and one million and a-half of miles due to the excentricity of the orbit of the earth.

312. **Greatest elongation.** — Owing to the ellipticity of the planet's orbit, the greatest elongation of Mercury is subject to some variation. Its mean amount is $22^\circ\cdot5$.

313. **Scale of the orbit relatively to that of the earth.** — The orbit of Mercury and a part of that of the earth are exhibited on their proper scale in *fig.* 55, where S E is the earth's distance from the sun, and $m\ m''\ m$ the orbit of the planet. The lines E m'' drawn from the earth touching the orbit of the planet determine the positions of the planet when its elongation is greatest east and west of the sun. The points m are the positions of the planet at inferior and superior conjunction.

314. **Apparent motion of the planet.** — The effects of the combination of the orbital motions of the planet and the earth upon the apparent place of the planet will now be easily comprehended.

Since the mean value of the greatest elongation m'' E S $=22\frac{1}{2}^\circ$. the arc $mm''=67\frac{1}{2}^\circ$ and therefore $m''\ m\ m''=67\frac{1}{2}^\circ\times 2=135^\circ$. The times of the greatest elongations east and west therefore divide the whole synodic period into two unequal parts, in one of which, that from the greatest elongation east through inferior conjunction to the greatest elongation west, the planet gains upon the earth 135°; and in the other, that from the greatest elongation west, through superior conjunction to the greatest elongation east, it gains $360^\circ-135^\circ=225^\circ$. Since the parts into which the synodic period is thus divided are proportional to these angles, they will be (taking the synodic period in round numbers as 116 days),

Fig. 55.

$$\frac{135}{360}\times 116 = 43\tfrac{1}{2}\text{ days.}$$

$$\frac{225}{360}\times 116 = 72\tfrac{1}{2}\text{ days.}$$

And since the former interval is divided equally by the epoch of inferior, and the latter by the epoch of superior, conjunction, it follows, that the intervals between inferior conjunction and greatest

elongation are 21¾ days, and the intervals between superior conjunction and greatest elongation are 36¼ days.

The interval between the times at which the planet is stationary, before and after inferior conjunction, is subject to some variation, owing to the excentricities of the orbits both of the planet and the earth, but chiefly to that of the planet's orbit, which is considerable. If its mean value be taken at 22 days, the angle gained by the planet on the earth in that interval being $68^\circ{\cdot}4$, the angular distances of the points at which the planet is stationary from inferior conjunction as seen from the sun would be $34^\circ{\cdot}2$, which would correspond to an elongation of about 21°, as seen from the earth. This result, however, is subject to very great variation, owing to the excentricity of the planet's orbit and other causes.

315. **Conditions which favour the observation of an inferior planet.**—These conditions are threefold: 1. The magnitude of that portion of the enlightened hemisphere which is presented to the earth. 2. The elongation. 3. The proximity of the planet to the earth.

Since it happens that the positions which render some of these conditions most favourable render others less so, the determination of the position of greatest apparent brightness is somewhat complicated. When the planet is nearest to the earth its dark hemisphere is presented towards us; besides which, being in inferior conjunction, it rises and sets with the sun, and is only present in the day time. At small elongations in the inferior part of the orbit its distance from the earth is not much augmented, but it is still overpowered by the sun's light, and would only appear as a thin crescent when it would be possible to see it. At the greatest elongation, when it is halved, it is most removed from the interference of the sun, but is brightest at a less elongation, even though it moves to a greater distance from the earth, since it gains more by the increase of its phase than it loses by increased distance and diminished elongation.

Owing to the very limited elongation of Mercury, that planet, even when its apparent distance from the sun is greatest, sets in the evening long before the end of twilight; and when it rises before the sun, the latter luminary rises so soon after it that it is never free from the presence of so much solar light, which renders it extremely difficult to see the planet with the naked eye.

In these latitudes Mercury is therefore only occasionally seen with the naked eye. It is said that Copernicus himself never saw this planet, a circumstance which, however, may have been owing, in a great degree, to the unfavourable climate in which he resided. In lower latitudes, where the diurnal parallels are more nearly vertical and the atmosphere less clouded, it is more frequently

visible, and there it is more conspicuous, owing to the short duration of twilight.

316. **Apparent diameter — its mean and extreme values.** — Owing to the variation of the planet's distance from the earth, its apparent diameter is subject to a corresponding change. At its greatest distance its apparent diameter is $4\frac{1}{2}''$, and at its least distance $11\frac{1}{2}''$, its value at the mean distance being $6\frac{1}{2}''$.

The apparent diameter of the moon being familiar to every eye supplies a convenient and instructive comparison by which the apparent magnitudes of other objects may be indicated, and we shall refer to it frequently for that purpose. The disk of the full moon subtends an angle of $1800''$ to the eye. It follows, therefore, that the apparent diameter of Mercury when it appears as a thin crescent near inferior conjunction is about the 150th part, near the greatest elongation it is the 280th part, and near superior conjunction the 400th part of the apparent diameter of the moon.

317. **Real diameter.**—The real diameter has been assumed, from some recent measures, to be about 3058 miles.

318. **Volume.**—Assuming that the diameter of Mercury equals 3058 miles, it follows that its volume would amount to about the 19th part of that of the earth.

The relative volumes are represented by M and E, *fig.* 56.

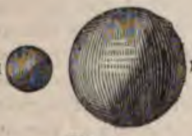


Fig. 56.

319. **Mass and density.**—Some uncertainty has hitherto attended the calculation of the density and mass of this planet, owing to the absence of a satellite. The disturbances produced by it upon the motion of Encke's comet (a body which will be described in another chapter) have, however, supplied the means of a closer approximation to it. By this means it has been found that if M′ express the mass of the planet, and M that of the earth, we shall have

$$\frac{M'}{M} = \frac{100}{1545};$$

so that the mass is $15\frac{1}{2}$ times less than that of the earth.

The density of the planet relatively to that of the earth, determined from the above, would equal 1·20. Other estimates make it 1·12. So that it may be inferred that the density of Mercury exceeds that of the earth by an eighth to a fifth; this result is, however, problematical.

320. **Solar light and heat.**—The apparent magnitude of the sun is greater than upon the earth, in the same ratio as the distance is less; and owing to the considerable ellipticity of Mercury's orbit,

it has apparent magnitudes sensibly different in different parts of Mercury's year. The apparent mean diameter of the sun as seen

Fig. 57.

Fig. 58.

from the earth being 32′ 4″, its apparent diameter seen from Mercury will be in perihelion 104′·3, in aphelion 68′·7, and at mean distance 82′·9.

Thus the apparent diameter when least, is twice, and when greatest, three times, that which the sun appears from the earth when at its mean magnitude.

In *figs.* 57, 58, the relative apparent magnitudes of the sun, as seen from the earth and from Mercury, at the mean distance and extreme distances, are represented at E, M, M′, and M″. If E be supposed to represent the apparent disk of the sun as seen from the earth, M will represent it as it appears to Mercury at the mean distance, M′ at aphelion and M″ at perihelion.

Since the illuminating and heating power of the sun's rays, whatever be the physical condition of the surface of the planet, must vary in the same proportion as the apparent area of the sun's disk, it follows, that the light and warmth produced by the sun on the surface of the planet will be greater in perihelion than in aphelion, in the ratio of 9 to 4, and, consequently, there must be a succession of seasons on this planet, depending exclusively on the ellipticity of the orbit, and having no relation to the direction of its axis of rotation or the position of the plane of its equator with relation to that of its orbit. The passage of the planet through its perihelion must produce a summer, and its passage through aphelion a winter, the mean temperature of the former, *ceteris paribus*, being above twice that of the latter.

If the axis of the planet be inclined to the plane of its orbit, another succession of seasons will be produced, dependent on such inclination and the position of the equinoxial points. If these points coincide with the apsides of the orbit, the summers and winters arising from both causes will either respectively coincide, or the summer from each cause will coincide with the winter from the other. In the former case the intensities of the seasons and their extreme temperatures will be augmented, by the coincidence, and

in the latter they will be mitigated, the summer heat from each cause tempering the winter cold from the other.

If, on the other hand, the line of apsides be at right angles to the direction of the equinoxes, the summer and winter from each cause will correspond with the spring and autumn from the other, and a curious and complicated succession of seasons must ensue, depending on the degree of obliquity of the axis of the planet, compared with the effects of the excentricity of its orbit.

In comparing the calorific influence of the sun on Mercury and the earth, it must be remembered that the actual temperature produced by the solar rays, depends on the density of the atmosphere through which they pass, by which the heat is collected and diffused. The density of the sun's rays above the snow-line in the tropics is as great as at the level of the sea, but the temperatures of the air and surrounding objects are extremely different. Notwithstanding, therefore, the greater density of the solar rays, the atmospheric conditions of the planet may be such that the superficial temperature may not be different from that of the earth.

The intensity of the solar light must be greater than at the earth in the ratio of four to one when the planet is in aphelion, and nine to one when in perihelion. Its effects on vision, however, may be rendered the same by the mere adaptation of the contractile power of the pupil of the eye. (O. 362.)

321. **Method of ascertaining the diurnal rotation of the planets.**—One of the most interesting objects of telescopic inquiry regarding the condition of the planets is, the question as to their diurnal rotation. In general, the manner in which we should seek to ascertain this fact would be, by examining with powerful telescopes the marks observable upon the disk of the planet. If the planet revolve upon an axis, these marks, being carried round with it, would appear to move across the disk, from one side to the other; they would disappear on one side, and, remaining for a time invisible, would reappear on the other, passing, as before, across the visible disk. Let any one stand at a distance from a common terrestrial globe, and let it be made to revolve upon its axis: the spectator will see the geographical marks delineated on it, pass across the hemisphere which is turned towards him. They will successively disappear and reappear. The same effects must, of course, be expected to be seen upon the several planets, if they have a motion of rotation resembling the diurnal motion of our globe.

322. **Difficulty of this question in the case of Mercury.**—This is a species of observation which has not yet been successfully made in the case of Mercury. Sir John Herschel, who has enjoyed more than common advantages for telescopic observation under different climates, affirms, that little more can be certainly affirmed of

Mercury than that it is globular in form, and exhibits phases, and that it is too small and too much lost in the constant and close effulgence of the sun to allow the further discovery of its physical condition. Other observers, however, claim the discovery of indications not only of rotation but other physical characters. Schröter says, that by examining daily the appearance of the cusps of the crescent, he ascertained that it has a motion of rotation in $24^h\ 5^m\ 28^s$.

323. **Alleged discovery of mountains.**—The same observer claims the discovery of mountains on Mercury, and even assigns their height, estimating one at 2132 yards, and another at 18,978 yards.

These observations, not having been confirmed, must be considered apocryphal.

III. Venus.

324. **Period.**—The next planet proceeding outwards from the sun is Venus, which revolves in an orbit within that of the earth, and which, after the sun and moon, is the most splendid object in the firmament.

The synodic period, ascertained by observation, is 584 days. Her mean sidereal period deduced from this is, therefore, 225 days.

By other methods it is more exactly determined to be 224·7 days.

If the earth's period be taken as the unit, that of Venus will, therefore, be 0·6125.

325. **Mean and extreme distances from the sun and earth.**—The distances of Venus from the earth at inferior conjunction, greatest elongation, and superior conjunction, are about

25,296,000 miles at inferior conjunction,
62,500,000 miles at greatest elongation,
157,564,000 miles at superior conjunction.

The excentricity of its orbit being less than 0·007, these distances from the earth are subject to very little variation from that cause. The extreme distance of the planet from the sun is

65½ millions of miles in perihelion, and
66½ „ „ aphelion.

The distances of Venus from the earth are subject therefore to an increase and diminution, amounting to half a million of miles, due to the excentricity of the planet's orbit, and one and a half million of miles due to that of the earth's orbit.

326. **Greatest elongation.**—The mean amount of the greatest elongation of Venus has been found by observation to be about 45° or 46°.

327. **Scale of the orbit relative to that of the earth.**—The relation of the orbit of Venus to the earth is represented in *fig.* 59, where S E represents the earth's distance from the sun, and v S v the mean diameter of the planet's orbit on the same scale. The angles S E v'' represent the greatest elongation of the planet, which is about 46°. The lesser elongations v''' E S are those at which the planet appears with less than a full disk, or gibbous, as at v''', or as a crescent, as at v'.

328. **Apparent motion.**—Since the mean value of the greatest elongation is ascertained to be 46°, the angle at the sun, v'' S E = 44°, and consequently the angle v'' S v'', included between the greatest elongations east and west, is 88°. Since the time taken by the planet to gain this angle upon the earth bears the same ratio to the synodic period as this angle bears to 360°, the intervals into which the synodic period is divided by the epochs of greatest elongation, are

$$\frac{88}{360} \times 584 = 142{\cdot}8 \text{ days.}$$

$$\frac{272}{360} \times 584 = 441{\cdot}2 \text{ days.}$$

The intervals between inferior conjunction and greatest elongation are therefore 71½ days, and the intervals between superior conjunction and greatest elongation are 220½ days.

Fig. 59.

329. **Stations and retrogression.**—From a comparison of the orbital motions and distances of the earth and planet, it is found that the epochs at which it is stationary are about twenty-one days before and after inferior conjunction. Now, since the planet gains 0°·6125 per day upon the earth, this interval corresponds to an angle of 12°·9 at the sun, which corresponds to an elongation of about 25° or 26°. The arc of retrogression is little less than a degree.

330. **Conditions which favour the observation of Venus.**—This planet presents itself to the observer under conditions in many respects more favourable

for telescopic examination than Mercury. The actual diameter of Venus is more than twice that of Mercury. It approaches nearer to the earth in the inferior part of its orbit in the ratio of 13 to 30. It elongates itself from the sun to the distance of 46°, while the elongation of Mercury is limited to 22½°. The latter is never seen, except in strong twilight. Venus, especially in the lower latitudes, is seen at a considerable elevation long after the cessation of evening and before the commencement of morning twilight, and when she has a gibbous or a crescent phase. The planet appears brightest when its elongation is about 40° in the superior part of her orbit.

331. **Evening and morning star.—Lucifer and Hesperus.**—This planet for these reasons is, next to the sun and moon, the most conspicuous and beautiful object in the firmament. When it has western elongation, it rises before the sun, and is called the MORNING STAR. When it has eastern elongation, it sets after the sun, and is called the EVENING STAR.

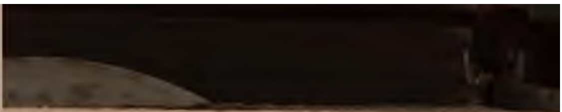
The ancients gave it in the former position, the name of LUCIFER (the harbinger of day), and in the latter that of HESPERUS.

332. **Apparent diameter.**—Owing to the great difference between its distance from the earth at inferior and superior conjunctions, the apparent diameter of this planet varies in magnitude within wide limits. At superior conjunction it is only 10″, from which to inferior conjunction it gradually enlarges until it becomes 62″, and in some positions even so much as 76″. At its greatest elongation its apparent diameter is about 25″, and at its mean distance 16½″.

333. **Difficulties attending the telescopic observation of Venus.**—Notwithstanding this, the greatest difficulties have attended the telescopic observation of this planet when any special accuracy is required. Its intense lustre dazzles the eye, and aggravates all the optical imperfections of the instrument. In some cases, however, the image of the planet is improved and the great lustre destroyed, if a slightly green-coloured glass be placed before the eye-glass of the telescope, in a similar manner as darkened glasses are used for observations of the sun.

The low altitudes at which the observations are generally made, constitute another difficulty, the irregular effects of refraction interfering materially with the appearance. Some observers have consequently contended that the best position for observations upon it, is near superior conjunction, when its phase is full, and when by proper expedients it may be observed at midday within a few degrees of the sun's disk.

The planet can, however, be favourably observed with a moderately good telescope, about the time of greatest elongation, during any



part of the day within the limits of three hours before and after the meridian passage, by taking the precaution of using the slightly coloured glass previously mentioned.

334. **Real diameter.** — The linear value of 1″ at Venus, when she appears as a thin crescent near her inferior conjunction, is 122·6 miles. At this distance her apparent diameter is 61″; and her real diameter about 7510 miles. The magnitude of Venus is, therefore, nearly equal to that of the earth.

335. **Mass and density.**—By the methods already explained, it has been ascertained that the mass of Venus is less than that of the earth in the ratio of 89 to 100; and as the volumes are nearly equal, their densities are also nearly equal.

336. **Superficial gravity.** — All the conditions which affect the gravity of bodies on the surface of Venus being the same, or nearly so, as those which affect bodies on the earth, the superficial gravity is nearly the same.

337. **Solar light and heat.** — The density of the solar rays is greater than upon the earth in the inverse ratio of the squares of the numbers 7 and 10, which express their distances from the sun. The intensity is, therefore, greater at Venus in the ratio of 2 to 1.

The relative apparent magnitudes of the sun's disk at Venus and the earth are represented at V and E, *fig.* 60. Owing to the very small excentricity of the orbit, this magnitude is not subject to any very sensible variation.

Fig. 60.

338. **Rotation — probable mountains.** — Although there is very little doubt of the fact that this planet has a diurnal rotation analogous to that of the earth, the observations which might have been expected to demonstrate it in a satisfactory manner have been obstructed by the causes already noticed (333). Nevertheless Cassini, in the 17th century, and Schröter towards the close of the 18th, with instruments very inferior to the telescopes of the present day, deduced from the phases a period of rotation in complete accordance with the results of the most recent observations.

These astronomers found that the points of the horns of the crescent observed between inferior conjunction and greatest elongation, appeared at certain moments to lose their sharpness, and to become as it were blunted. This appearance was, however, of very short duration, the horn after some minutes always recovering its sharpness. Such an effect would obviously be produced by a local irregularity of surface on the planet, such as a lofty mountain which would throw a long shadow over that part of the surface

which would form the point of the horn. Now, admitting this to be the cause of the phenomenon, it ought to be reproduced by the same mountain at equal intervals, this interval being the time of rotation of the planet. Such a periodical recurrence was accordingly ascertained.

339. **Observations of Cassini, Herschel, and Schröter.**— From such observations the elder Cassini, so early as 1667, inferred the time of rotation of the planet to be $23^h\ 16^m$, a period not very different from that of the earth. Soon after this, Bianchini, an Italian astronomer, published a series of observations tending to call in doubt the result obtained by Cassini, and showing a period of 576 hours. Sir William Herschel resumed the subject, aided by his powerful telescopes, in 1780, but without arriving at any satisfactory result, except the fact that the planet is invested with a very dense atmosphere. He found the cusps (contrary to the observations of Cassini, and, as we shall see, of more recent astronomers) always sharp, and free from irregularities. Schröter made a series of most elaborate observations on this planet, with a view to the determination of its rotation. He considered not only that he saw periodical changes in the form of the points of the horns, but also spots, which had sufficient permanency to supply satisfactory indications of rotation. From such observations he inferred the time of rotation to be $23^h\ 21^m\ 7^s{\cdot}98$. From observations upon the horns, he inferred also that the southern hemisphere of the planet was more mountainous than the northern; and he attempted from observations on the bluntness periodically produced on the southern point of the crescent, to estimate the height of some of the mountains, which he inferred to amount to the almost incredible altitude of twenty-two miles.

340. **Observations of MM. Beer and Mädler.— Time of rotation.**—Although the estimate of the planet's rotation resulting from the observations of Schröter, corroborating those of Cassini, has been generally accepted by the scientific world, the question was not regarded as definitively settled; and a series of observations was made by MM. Beer and Mädler, between 1833 and 1836, which went far to confirm the conclusions of Cassini and Schröter; and the still more recent observations of De Vico at Rome may be considered as removing all doubt that the period of the planet's rotation does not vary much from $23\frac{1}{4}^h$.

341. **Beer and Mädler's diagrams of Venus.**—In *fig.* 61, are represented a series of eighteen diagrams of the planet, selected from a much greater number made by MM. Beer and Mädler at the dates indicated above. These drawings were taken when the planet was approaching inferior conjunction, the planet being observed either before sunset or during twilight.

If the surface of the planet were exempt from considerable inequalities, the concave edge of the crescent would be a sensible ellipse, subject to no other deficiency of perfect regularity and sharpness, save such as might be explained by the gradual faintness

Fig. 61.

of illumination due to the atmosphere of Venus. The mere inspection of the diagrams is enough to show that such is not the appearance of the disk. Irregularities of curvature and of the forms of the cusps are apparent, which can only arise from corresponding irregularities of the surface of the planet. If the want of sharpness in the horns of the crescent arose from any effect produced by the terrestrial atmosphere on the optical image of the disk it would equally affect both cusps. Several of the diagrams, for example *figs.* 1, 2, 3, 7, 8, 15, 17, are at variance with such an hypothesis, the cusps being obviously different in form.

In corroboration of the observations of Schröter, it was ascertained that the southern cusp was subject to greater and more frequent changes of form than the northern, from which it was inferred that the southern hemisphere of the planet is the more mountainous. It is remarkable that the same character is found to prevail on the moon.

It was not only observed that the irregularities of the concave edge of the crescent were subject to a change visible from 5^m to 5^m, but that the same forms were reproduced after an interval of $23\frac{1}{4}^h$, subject to an error not exceeding from 5 to 10 minutes.

342. **More recent observations of De Vico.**—M. De Vico, observing at a still later date at Rome, favoured by the clear sky of Italy, made several thousand measurements of the planet in its phases, the general result of which is in such complete accordance

with those of MM. Beer and Mädler, that the fact of the planet's rotation may be now regarded as satisfactorily demonstrated, and that its period does not differ much from $23^h\ 15^m$.

343. **Direction of the axis of rotation unascertained.**— If such difficulties have attended the mere determination of the rotation, it will be easily conceived that those which have attended the attempts to ascertain the direction of the axis of rotation have been much more insurmountable. The observations above described, by which the rotation has been established, supply no ground by which the direction of the axis could be ascertained. No spot has been seen, the direction of whose motion could indicate that of the axis. It was conjectured, with little probability, by some observers, that the axis was inclined to the orbit at the angle of $75°$. This conjecture, however, has not been confirmed.

344. **Twilight on Venus and Mercury.**— The existence of an extensive twilight in these planets has been well ascertained. By observing the concave edge of the crescent which corresponds to the boundary of the illuminated and dark hemispheres, it is found that the enlightened portion does not terminate suddenly, but there is a gradual fading away of the light into the darkness, produced by the band of atmosphere illuminated by the sun which overhangs a part of the dark hemisphere, and produces upon it the phenomena of twilight.

Some observers have seen on the dark hemisphere of the planet *Venus* a faint reddish and greyish light, visible on parts too distant from the illuminated hemisphere to be produced by the light of the sun. It was conjectured that these effects are indications of the play of some atmospheric phenomena in this planet similar to the *aurora borealis.*

It may be stated generally, that so far as relates to the physical condition of the inferior planets, the whole extent of our certain knowledge of them is, that they are globes like the earth, illuminated and warmed by the sun; that they are invested with atmospheres probably more dense than that of the earth; and since observations render probable the existence of vast masses of clouds on Venus, if not on Mercury, analogy justifies the inference that liquids exist on these planets.

345. **Spheroidal form unascertained — suspected satellite.** — One of the phenomena from which the rotation, as well as the direction of the axis, might be inferred, is the spheroidal form of the planet. To ascertain this by observations of the disk, it would be necessary to see the planet with a full phase. But when the inferior planets have that phase, they are near superior conjunction, and therefore lost in the solar light. It has been nevertheless

contended, that when Venus is most remote from her node, she is sufficiently removed from the plane of the ecliptic to be observed with a good telescope at noon when in superior conjunction. No observation, however, of this kind has ever yet been made, and the spheroidal form of the planet is unascertained.

This planet was observed with the transit-circle at the Royal Observatory, Greenwich, on the 19th of February, 1858, when very near superior conjunction, the interval of time between the passages of the planet and sun over the meridian being less than six minutes. The image of Venus was, however, very tremulous.

Several observers of the last two centuries concurred in maintaining that they had seen a satellite of Venus. Cassini, the elder, imagined he saw such a body near the planet on the 25th of January, 1672, and again on the 27th of August, 1686; Short, the well-known optical instrument maker, on the 3rd of November, 1740; Montaigne, the French astronomer, in May, 1761; several observers in March, 1764, all agree in reporting observations of such a body. In each case the phase was similar to that of Venus, and the apparent diameter about a fourth of that of the planet. By collecting these observations, Lambert computed the orbit of the supposed satellite.

In opposition to all this, it may be stated that notwithstanding the immense improvement in optical instruments, and especially in the construction of telescopes of power far surpassing any of which the observers before the present century were in possession, no trace of such a body has been detected, although observers have increased in number, activity, and vigilance, in a proportion greater still than that of the improvement of telescopes. It must, therefore, be concluded, at least for the present, that the supposed appearances recorded by former observers were illusive.

IV. Mars.

346. **Position in the system.**—Proceeding outwards from the sun, the next planet in the order of distance is the earth. The next in succession is Mars, whose orbit circumscribes that of the earth.

347. **Period.**—The synodic period of Mars is found by observation to be 780 days, and the sidereal period 686·98 days.

The earth's period being taken as the unit, the period of Mars will therefore be 1·881.

348. **Mean distance from the sun.**—The mean distance of Mars from the sun is 1·5237, that of the earth being unity; or in round numbers about 139 millions of miles.

349. **Excentricity—mean and extreme distances from the**

sun and earth.—The excentricity of the orbit of Mars being about 0·0933, the distance from the sun is subject to a variation, the extreme amount of which is less than one-tenth of its mean value. The extreme distances are

152¼ millions of miles in aphelion,
126¼ millions of miles in perihelion.

It appears, therefore, that the mean distances of the planet from the earth are

In opposition	-	47¾ millions of miles,
In conjunction	-	230¾ millions of miles,
In quadrature	-	104 millions of miles,

These distances are subject to variation, whose extreme limit is about 15 millions of miles, owing to the combined effects of the excentricities of the two orbits. Although the mean distance of the planet in opposition from the earth is about half the distance of the sun, it may in certain positions of the orbit come within a distance of 35 hundredths of the sun's distance. In the opposition which took place in September, 1830, the distance of the planet was only 38 hundredths of the sun's mean distance.

350. **Scale of orbit relatively to that of the earth.**—If S, *fig.* 62, represent the position of the sun, and S M the distance of Mars, the orbit of the earth will be represented by E E″E‴E′.

351. **Division of the synodic period.**—The earth is at E‴ when Mars is in conjunction, at E′ when in quadrature west of the sun, at E when in opposition, and at E″ when in quadrature east of the sun.

Fig. 62.

The angle of elongation S E′ M being 90°, and the mean value of S M being 1·52, that of S E′ being expressed by 1, it follows that the angle E′S M will be about 48°, and therefore E′S E‴ $=180°-48°=132°$.

Since the synodic period is 780 days, the mean time between quadrature and opposition will be

$$\frac{48}{360} \times 780 = 104 \text{ days};$$

and the mean time between quadrature and conjunction will be

$$\frac{132}{360} \times 780 = 286 \text{ days}.$$

352. **Apparent motion.**—The various changes of the apparent positions of the planet and sun during the synodic period may, therefore, be easily explained. At conjunction the earth being at E‴, the planet and sun pass the meridian together. In this case, the planet being above the horizon only during the day, is not visible. After conjunction, the planet passes the meridian in the forenoon, and is therefore visible above the eastern horizon before sunrise. Before conjunction it passes the meridian in the afternoon, and is therefore visible above the western horizon after sunset.

At the time of the western quadrature, the earth being at E′, the planet passes the meridian about 6 A.M., and at the time of western quadrature, the earth being at E″, it passes the meridian about 6 P.M. The planet has these positions about 286 days, more or less, after and before its conjunction.

At the time of opposition, the earth being at E, the planet passes the meridian at midnight; and is therefore above the horizon from sunset till sunrise. Before opposition it passes the meridian before midnight, and is above the horizon chiefly during the later part of the night, and after opposition it passes the meridian after midnight, and is therefore above the horizon chiefly during the earlier part of the night.

The interval during which it is visible more or less in the absence of the sun, being that during which it passes from western to eastern quadrature through opposition is, in the case of Mars, 208 days.

353. **Stations and retrogression.**—The elongations at which Mars is stationary, and the lengths of his arc of retrogression, vary to some extent with the distances of the planet from the sun and earth, which distances depend on the ellipticity of the two orbits, and the direction of their major axes. In 1860, Mars was in opposition on the 17th of July, and was stationary on the 17th of June and 18th of August. The right ascension on these days was,

17th of June	R.A.	=	$20^h\ 13^m\ 49^s$
18th of August	R.A.	=	19 27 19
Difference		=	46 30

It follows, therefore, that the extent of retrogression in right

ascension at this opposition was $46^m\ 30^s$, which reduced to angular magnitude is $11^\circ\ 37'\ 30''$.

354. **Phases.**—At opposition and conjunction the same hemisphere being turned to the earth and sun, the planet appears with a full phase. In all other positions the lines drawn from the planet to the earth and sun, making with each other an acute angle of greater or less magnitude, the phase will be deficient of complete fulness, and the planet will be gibbous, more so the nearer it is to its quadrature, in which position the lines drawn to the earth and sun make the greatest possible angle, which being the complement of E′ S M, *fig.* 62, will be $90^\circ - 48^\circ = 42^\circ$. Of the entire hemisphere presented to the earth, 138° will therefore be enlightened and 42° dark. The corresponding form of the disk, as can easily be deduced from the common principles of projection, will be that which is represented in *fig.* 63, the dark part being indicated by the dotted line.

The gibbosity will be less, the nearer the planet approaches to opposition or conjunction.

355. **Apparent and real diameter.**—The apparent diameter of Mars in opposition varies between rather wide limits, in consequence of the variation of its distance from the earth in that position, arising from the causes explained above. When at its mean distance at opposition the apparent magnitude does not exceed $16''$, and at conjunction it is reduced to $3''\cdot 7$.

Fig. 63.

In 1830, soon after opposition, when its distance from the earth was 38·4 millions of miles, it exhibited a diameter of $23\frac{1}{2}''$; the linear value of $1''$ at that distance being 185·7 miles, which gives for the real diameter 4363 miles.

356. **Solar light and heat.**—The mean distance of the earth from the sun being less than that of Mars in the ratio of 10 to 15, the apparent diameter of the sun as seen from Mars will be less than its diameter as seen from the earth in the same ratio. If E, *fig.* 64, represent the apparent disk of the sun as seen from the earth, M will represent its apparent disk as seen from Mars.

Fig. 64.

Since the density of the solar radiation decreases as the square of the distance increases, its density at Mars will be less than at the earth in the ratio of 4 to 9.

So far as the illuminating and heating powers of the solar rays depend on their density, they will, therefore, be less in the same proportion.

357. **Rotation.**—There is no body of the solar system, the moon alone excepted, which has been submitted to such rigorous and successful telescopic examination as Mars. Its proximity to the earth in opposition, when it is seen on the meridian at midnight with a full phase, affords great facility for this kind of observation.

By observing the permanent lineaments of light and shade exhibited by the disk, its rotation on its axis can be distinctly seen, and has been ascertained to take place in $24^h\ 37^m\ 23^s$, the axis on which it revolves appearing to be inclined to the plane of the planet's orbit at an angle of 28° 27′. The exact direction of the axis is, however, still subject to some uncertainty.

358. **Days and nights.**—It thus appears that the days and nights in Mars are nearly the same as on the earth, that the year is diversified by seasons, and the surface of the planet by zones and climates not very different from those which prevail on our globe. The tropics, instead of being 23° 28′, are 28° 27′ from the equator, and the polar circles are in the same proportion more extended.

359. **Seasons and climates.**—The year consists of 668 Martial days and 16 hours, the Martial being longer than the terrestrial day in the ratio of 100 to 97.

Owing to the excentricity of the planet's orbit, the summer on the northern hemisphere is shorter than on the southern in the ratio of 100 to 79, but owing to the greater proximity of the sun, the intensity of its light and heat during the shorter northern summer is greater than during the longer southern summer in the ratio of 145 to 100. From the same causes, the longer northern winter is less inclement than the shorter southern winter in the same proportion.

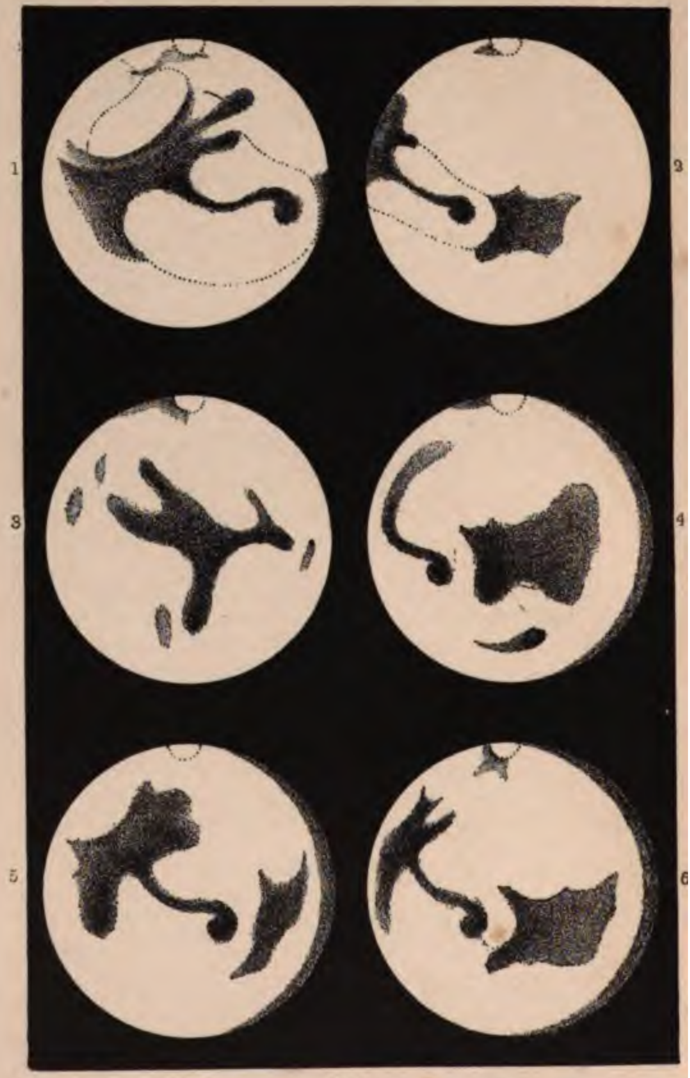
There is thus a complete compensation in both seasons in the two hemispheres.

The duration of the seasons in Martial days in the northern hemisphere is as follows:—spring 192, summer 180, autumn 150, winter 147.

360. **Observations and researches of Messrs. Beer and Mädler.**—It is mainly to the persevering labours of these eminent observers that we are indebted for all the physical information we possess respecting the condition of the surface of this planet. Their observations, commenced at an early epoch, were regularly organised at the time of the opposition of 1830, with a view to

[redacted]

XVII.



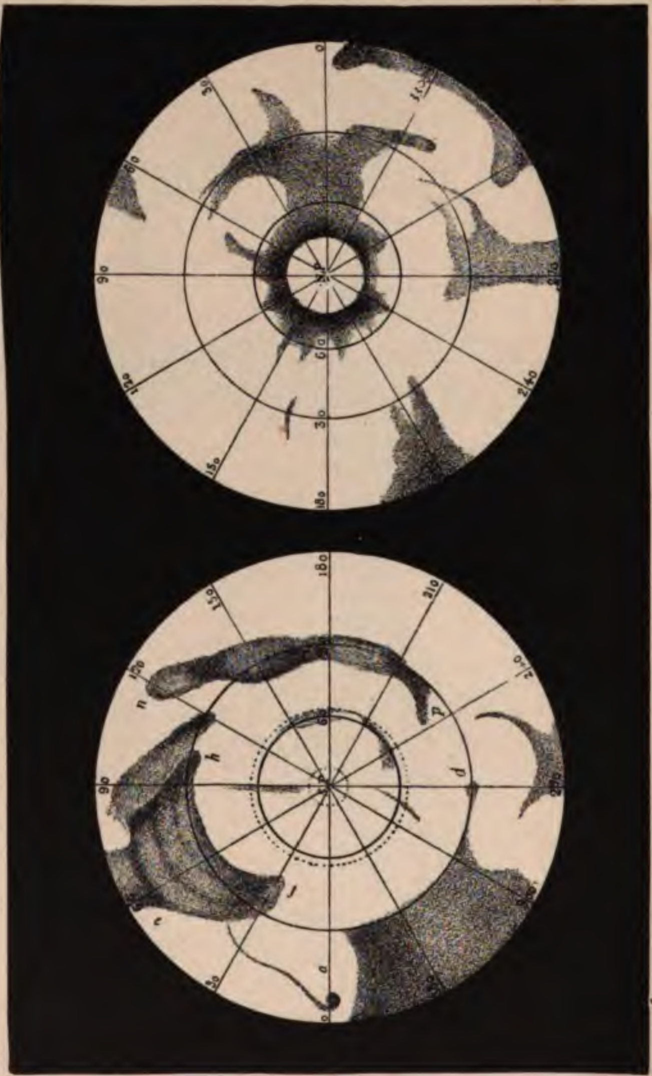
MARS.

From Telescopic Drawings by MM. Beer & Mädler.

1. Sept. 14, 10 h. 30 m.
2. Sept. 14, 13 h.
3. Sept. 15, 10 h. 6 m.
4. Oct. 14, 7 h. 37 m.
5. Oct. 19, 8 h. 13 m.
6. Oct. 20, 10 h. 20 m.

[redacted]

XVIII.



MARS.

Telescopic projections of the two Hemispheres by M. Mädler.

ascertain with certainty and precision the time of rotation of the planet, the position of its axis, and, so far as might be practicable, a survey of its surface. These observations have been continued during every succeeding opposition, in which the planet having northern declination rose to a sufficient altitude, and was made visible by a telescope by Fraunhofer of four and a half feet focal length, parallactically mounted, and moved by clockwork, so as to keep the planet in the field of view notwithstanding the diurnal motion of the earth.

361. **Areographic character.**—That many of the lineaments observed are areographic, and not atmospheric, is established beyond all contestation by their permanency. They are not always visible, and when visible not always equally distinct; but are observed to retain the same forms, no matter how distant may be the intervals at which they may be submitted to examination. The elaborate researches and observations of MM. Beer and Mädler, which commenced with the opposition of 1830, were continued with unwearied assiduity in every succeeding opposition of the planet for twelve years, so far as the varying declination and the state of the weather at the epochs of the oppositions permitted. The same spots, characterised by the same forms, and the same varieties of light and shade, were seen again and again in each succeeding opposition. Changes of appearance were manifest, but through those changes the permanent features of the planet were always discerned; just as the seas and continents of the earth may be imagined to be distinguishable through the occasional openings in the clouds of our atmosphere by a telescopic observer stationed on Mars.

362. **Telescopic views of Mars—areographic charts of the two hemispheres.**—A large collection of drawings of the various hemispheres of Mars presented to the observer has been made by MM. Beer and Mädler. Thirty-five were made during the opposition of 1830, upwards of thirty during that of 1837, and forty during that of 1841, from a comparison of which, charts were made, showing the permanent areographic lineaments of the northern and southern hemispheres.

In Plate XVII. we have given six views, selected from those of Beer and Mädler, with the dates subjoined. In Plate XVIII. are given the areographic charts of the two hemispheres. It will be observed, that as each spot approaches the edge of the disk, its apparent form is modified by the effect of foreshortening, owing to the obliquity of the surface of the planet to the visual ray.

363. **Polar snow observed.**—All the lineaments exhibited in these drawings were found to be permanent, except the remarkable white spots which cover the polar regions. These circular areas

presented the appearance of a dazzling whiteness, and one of them was so exactly defined and so sharply terminated, that it seemed like the full disk of a small and very brilliant planet projected upon the disk, and near the edge of a larger and darker one. The appearance, position, and changes of these white polar spots have suggested to all the observers who have witnessed them, the supposition that they proceed from the polar snows accumulated during the long winter, and which, during the equally protracted summer by exposure to the solar rays, more full by 7° than at the poles of the earth, are partially dissolved, so that the diameter of the snow circle is diminished.

The increase and diminution of this white circle takes place at epochs and in positions of the axis of the planet such as are in complete accordance with this supposition.

364. **Position of areographic meridians determined.** — The leg and foot-shaped spot marked *p n* in the southern hemisphere, was distinctly seen and delineated in all the oppositions. This was one of the spots from the apparent motion of which the time of rotation was deduced.

The spot *a* in the southern hemisphere connected with a large adjacent spot by a sinuous line, was also one of those whose position was most satisfactorily established. This spot was selected, as the observatory of Greenwich has been upon the earth, to mark the meridian from which longitudes are reckoned.

The spot *e f h*, chiefly situate in the southern, but projecting into the northern hemisphere, between the 90th and 105th degrees of longitude, was also well observed on repeated occasions.

According to Mädler, the reddish parts of the disk are chiefly those which correspond to 40° long. and 15° lat. S.

The two concentric dotted circles marked round the south pole, indicate the limits of the white polar spot as seen on different occasions in 1830 and 1837. The redness of this planet is much more remarkable to the naked eye than when viewed with the telescope. In some cases, during the observations of MM. Beer and Mädler, no redness was discoverable, and when it was perceived it was so faint that different observers at the same moment were not agreed as to its existence. It was found that the prevailing colour of the spots was generally yellow rather than red.

Independently of any effect which could be ascribed to projection or foreshortening, it was found that the lineaments were always seen with much greater distinctness near the centre of the disk than towards its borders. This is precisely the effect which might be expected from a dense atmosphere surrounding the planet.

365. **Possible satellite of Mars.** — Analogy naturally suggests the probability that the planet Mars might have a moon. These

attendants appear to be supplied to the planets in augmented numbers as they recede from the sun; and if this analogy were complete, it would justify the inference that Mars must at least have one, being more remote from the sun than the earth, which is supplied with a satellite. No moon has ever been discovered in connection with Mars. It has, however, been contended that we are not therefore to conclude that the planet is destitute of such an appendage; for as all secondary planets are much less than their primaries, and as Mars is by far the smallest of the superior planets, its satellite, if such existed, must be extremely small. The second satellite of Jupiter is only the forty-third part of the diameter of the planet; and a satellite which would only be the forty-third part of the diameter of Mars, would be under one hundred miles in diameter. Such an object could scarcely be discovered even by powerful telescopes, especially if it do not recede far from the disk of the planet.

The fact that one of the satellites of Saturn has been discovered only within the last few years, renders it not altogether improbable that a satellite of Mars may yet be discovered.

CHAPTER XV.

THE PLANETOIDS.

366. **A vacant place in the planetary series.**—At a very early epoch in the progress of astronomy it was observed that the progression of the distances of the planets from the sun was characterised by a remarkable numerical harmony, in which nevertheless a breach of continuity existed between Mars and Jupiter. This arithmetical progression was first loosely noticed by Kepler, but it was not until towards the close of the last century, that the more exact conditions of the law and the close degree of approximation with which it was fulfilled, with the exception just noticed, was fully explained.

This numerical relation prevails between the distances of the successive orbits of the other planets measured from that of the planet Mercury. It was observed that such distances formed very nearly a series in duple progression, so that each distance is twice the preceding one, with the sole exception already mentioned. Although this law is not fulfilled, like those of Kepler, with numerical precision, there is nevertheless so striking an approximation to it, as to produce a strong impression that it must be founded upon some physical cause, and not merely accidental. To show the near

approximation to the exact fulfilment of this law, we have placed in the following table the succession of calculated distances from Mercury's orbit, which will exactly fulfil the law, in juxtaposition with the actual distances of the planets, the earth's distance from the sun being the unit.

	Calculated Distance from Mercury.	Actual Distance from Mercury.
Venus - - - -	0·3362	0·3362
Earth - - - -	0·6724	0·6129
Mars - - - -	1·3448	1·1366
Absent planet - - -	2·6896	
Jupiter - - - -	5·3792	4·8157
Saturn - - - -	10·7584	9·1518
Uranus - - - -	21·5168	18·7955

By comparing these numbers, it will be apparent that although the succession of distances does not correspond precisely with a numerical series in duple progression, there is nevertheless a certain approach to such a series, and at all events, a glaring breach of continuity between Mars and Jupiter.

Towards the close of the last century, Professor Bode, of Berlin, revived this question of a deficient planet, and gave the numerical progression which indicated its absence in the form in which it has just been stated; and an association of astronomers was formed under the auspices of the celebrated Baron de Zach, of Gotha, for the express purpose of organising and prosecuting a course of observation, with the special purpose of searching for the supposed undiscovered member of the solar system. The very remarkable results which have followed this measure, the consequences of which have not even yet been fully developed, will presently be apparent.

367. **Discovery of Ceres.** (1)—On the 1st of January, 1801, being the first day of the present century, Professor Piazzi, observing in the fine serene sky of Palermo, noticed a small object of about the 7th or 8th magnitude which was not registered in the catalogues of stars. On the night of the 2nd, on again observing it, he found that its position relative to the surrounding stars was sensibly changed. The object appearing to be invested with a nebulous haze, was first considered a comet, and M. Piazzi announced it as such to the scientific world. An approximate orbit being however computed by Professor Gauss, of Göttingen, it was found to have a period of 1652 days, and a mean distance from the sun expressed by 2·735, that of the earth being 1.

By comparing this distance with that given in the preceding table, at which a planet was presumed to be absent, it will be seen that the object thus discovered filled the place with striking arithmetical precision.

Piazzi gave to this new member of the system the name CERES.

The sidereal periods and mean distances from the sun of the planetoids, determined from the most recent elements, will be found in the concluding chapter.

368. **Discovery of Pallas.** (2)—Soon after the discovery of Ceres the planet passing into conjunction ceased to be visible. In searching for it after emerging from the sun's rays, in March 1802, Dr. Olbers noticed on the 28th a small star in the constellation of Virgo, at a place which he had examined in the two preceding months, and where he knew that no such object was *then* apparent. It appeared as a star of about the seventh magnitude, the smallest which is visible without a telescope. In the course of a few hours he found its position visibly changed in relation to the surrounding stars. In fact the object proved to be another planet bearing a striking analogy to Ceres, and what was then totally unprecedented in the system, moving in an orbit at very nearly the same mean distance from the sun, and having therefore nearly the same period.

Dr. Olbers called this planet PALLAS.

The magnitude of Pallas when in that portion of its orbit where its distance from the earth is the greatest, is very minute; and is only visible with the assistance of telescopes furnished with object-glasses of considerable aperture.

369. **Olbers' hypothesis of a fractured planet.**—This circumstance, combined with the exceptional minuteness of these two planets, suggested to Olbers the startling, and then, as it must have appeared, extravagantly improbable hypothesis, that a single planet of the ordinary magnitude existed formerly at the distance indicated by Bode's analogy,—that it was broken into small fragments either by internal explosion from some cause analogous to volcanic action, or by collision with a comet,—that Ceres and Pallas were two of its fragments, and that it was very likely that many other fragments, smaller still, were revolving in similar orbits, many of which might reward the labour of future observers who might direct their attention to these regions of the firmament.

In support of this curious conjecture it was urged that in the case of such a catastrophe as was involved in the supposition, the fragments, according to the established laws of physics, would necessarily continue to revolve in orbits not differing much in their mean distances from that of the original planet; that the obliquities of the orbits to each other and to that of the original planet might be subject to a wider limit; that the excentricities might also have exceptional magnitudes; and, finally, that such bodies might be expected to have magnitudes so indefinitely minute as to be out of all analogy or comparison, not only with the other primary planets, but even with the smallest of the secondary ones.

Ceres and Pallas both were so small as to elude all attempts to estimate their diameters, real or apparent. They appeared like stellar points with no appreciable disk, but surrounded with a nebulous haziness, which would have rendered very uncertain any measurement of an object so minute. Sir W. Herschel thought that Pallas did not exceed 75 miles in diameter. Others have admitted that it might measure a few hundred miles. Ceres is still smaller. Some of the most minute of these bodies which have been more recently discovered, are supposed to be only a few miles in diameter.

The obliquity of the orbit of Ceres to the plane of the ecliptic is above 10½° and that of Pallas more than 34½°. Both planets therefore, when most remote from the ecliptic, pass far beyond the limits of the zodiac, and differ in obliquity from each other by a quantity far exceeding the entire inclination of any of the older planets.

It was further observed by Dr. Olbers, that at a point near the descending node of Pallas the orbits of the two planets very nearly coincided.

Thus it appeared that all the conditions which rendered these bodies exceptional, and in which they differed from the other members of the solar system, were precisely those which were consistent with the hypothesis of their origin advanced by Dr. Olbers.

370. **Discovery of Juno.** (3)—A year and a half elapsed before any further discovery was produced to favour this hypothesis. Meanwhile observers did not relax their zeal and their labours, and on the 1st of September, 1804, at ten o'clock P. M., Professor Harding, of Lilienthal, Germany, discovered another minute planet, which observation soon proved to agree in all its essential conditions with the hypothesis of Olbers, having a mean distance very nearly equal to those of Ceres and Pallas, an exceptional obliquity of 13°, and a considerable excentricity.

This planet was named JUNO.

Juno has the appearance of a star of the 8th magnitude, when in the most favourable position of its orbit for observation, and is of a reddish colour. It was discovered with a very ordinary telescope of 30 inches focal length and 2 inches aperture.

371. **Discovery of Vesta.** (4)—On the 29th of March, 1807, Dr. Olbers discovered another planet under circumstances precisely similar to those already related in the cases of the former discoveries. The name VESTA was given to this planet, which, in its minute magnitude and the character of its orbit, was analogous to Ceres, Pallas, and Juno.

Vesta is the brightest and apparently the largest of all this

group of planets, and when in opposition, appears as a star of the seventh magnitude, and may be sometimes distinguished by good and practised eyes without a telescope. Observers differ in their impressions of the colour of this planet. Harding and other German observers consider her to be reddish; others contend that she is perfectly white. Mr. Hind says that he has repeatedly examined her under various powers, and always received the impression of a pale yellowish cast in her light.

372. **Discovery of the other Planetoids.**—The labours of the observers of the beginning of the century having been now prosecuted for some years without further results, were discontinued, and it is probable that but for the admirable charts of the stars which have been since published, no other members of this remarkable group of planets would have been discovered. These charts, however, containing all the stars up to the 9th or 10th magnitude, included within a zone of the firmament 30° in width, extending to 15° on each side of the celestial equator, supplied so important and obvious an instrument of research, that the subject was again resumed with a better prospect of successful results. It was only necessary for the observer, map in hand, to examine, degree by degree, the zone within which such bodies are known to move, and to compare, star by star, the heavens with the map. When a star is observed which is not marked on the map, it is watched from hour to hour, and from night to night, though, in general, observations made at intervals of a few hours are sufficient to detect its planetary nature, provided the suspected object be a planet. If it do not change its position it must be inferred that it has been omitted in the construction of the map, and it is marked upon it in its proper place. If it change its position it must be inferred to be a planet, and its orbit is then calculated as soon as the required number of observations are made, which are necessary for the determination of its elements.

The mean distances from the sun of all the planetoids place them, without exception, between the orbits of Mars and Jupiter, and their minuteness of volume, and the very variable obliquities and excentricities of their orbits, cause them all to resemble the first four discovered in the beginning of the century, and, therefore, in complete accordance with the conditions mentioned in the curious hypothesis of Dr. Olbers, regarding the possibility of a fractured planet (369).

Astræa (5).—By the means already explained, M. Hencke, an amateur observer residing at Driessen in Prussia, discovered on the 8th of December, 1845, another of these small planets, which has been named Astræa.

The discovery of this planet created considerable excitement

amongst astronomers, no addition to the known planetary system having taken place since Vesta was discovered in 1807. It appears that M. Hencke, though not a professional astronomer, had availed himself for about fifteen years of the Berlin charts, which included stars down to the 9th magnitude situated in that part of the heavens in which the small planets are generally found. A portion of these charts was published, consisting of about two-thirds of the hours of right ascension, including 15° north and south declination. All honour should be given to the authors of these valuable results of astronomical research, as without them we might probably not have known of the existence of the numerous bodies which form the main subject of the present chapter.

On the evening of the 8th of December, 1845, M. Hencke, while examining a portion of the heavens in the fourth hour of right ascension, noticed a star of the ninth magnitude, which had no appearance in the chart; from his familiarity with that part of the heavens, he felt assured that the star was never previously in that position. He communicated his suspicions of the discovery of a new planet to M. Encke and M. Schumacher, who, after having confirmed the discovery from observations made at Berlin and Altona, announced publicly to the astronomical world this interesting addition to the list of planetoids.

Though discovered by optical means of no great power, and by an amateur observer, whose habits of business would lead him to other pursuits, we must always consider that this discovery gave birth to that desire for astronomical research, which at the present time (January 1867) has resulted in increasing the known bodies of the planetary system to such an extent, that the planetoids now number ninety-one, while scarcely a year passes without one or more fresh discoveries being made.

Astræa shines, when in its most favourable position, as a star of the ninth magnitude, but at other times its faintness prevents any observation, unless the observer be provided with an instrument with an object-glass of considerable aperture.

Hebe 6.—On the 1st of July, 1847, M. Hencke was again rewarded for his devotion by the discovery of Hebe. It first appeared of the ninth magnitude, but speedily became fainter, and was generally visible as a ruddy star of the tenth magnitude.

The maximum magnitude of this planet is about the seventh or eighth, and the minimum, the eleventh.

Iris 7.—Mr. Hind is the principal English astronomer who has devoted much attention to this branch of astronomical discovery, and can claim the honour of being the discoverer of ten of these minute objects. Mr. Hind, since the latter part of 1844, has directed the private observatory of Mr. Bishop, in the Regent's

Park, which is furnished with a telescope, equatorially mounted, capable of being employed in the most delicate researches.

Iris was discovered on the evening of the 13th of August, 1847; a systematic examination of the heavens having been commenced some months previously. Whilst scrutinising the heavens in the vicinity of 63 Sagittarii, Mr. Hind noticed a star of the eighth magnitude, which had escaped observation at any former time. An hour was sufficient to show its planetary nature, its position having retrograded, with respect to other stars, two seconds in that interval of time.

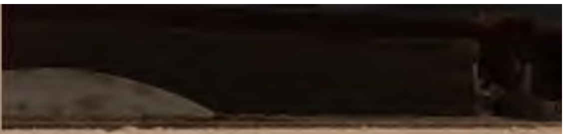
The maximum brilliancy of Iris is about the eighth magnitude, decreasing in other positions of its orbit to the tenth.

Flora (8).—This planet was also discovered by Mr. Hind. On the 18th of October, 1847, he noticed a star of the eighth or ninth magnitude, in a position in which it was never previously visible. Confirmation of the discovery was not obtained for some hours in consequence of cloudy weather, but on the 19th at 3^h A.M., an interval of four hours showed that the position of the object had changed in a direct motion about two seconds of time. This alteration was sufficient to assure the observer of its planetary nature.

The magnitude of Flora varies from the eighth or ninth to about the eleventh, according to its distance from the earth. When favourably seen, Mr. Hind has fancied he could perceive a measurable disk, but he cannot place implicit confidence in the observations.

Metis (9).—The next planet in order of discovery is due to Mr. Graham, assistant at the private observatory of Markree Castle, Ireland, under the direction of Mr. Cooper. Metis was found, like those preceding, by noticing the appearance of an object which was not recorded in the chart which was being compared with the corresponding part of the heavens. On the 25th of April, 1848, a star was suspected, and was noted down for re-examination. On the succeeding evening it was found to have retrograded one minute and its planetary nature established. When detected, the planet was of the tenth magnitude; in more favourable positions its appearance increases considerably in brightness.

Hygeia (10).—The zeal for astronomical discovery could not be supposed to remain in northern latitudes without drawing the attention of astronomers in the south of Europe, who are, fortunately for this purpose, accustomed to a clearer atmosphere than is generally found in England or Germany. M. de Gasparis of Naples was the first to enter the field, by the discovery of Hygeia on the 12th of April, 1849. M. de Gasparis was comparing the heavens with Steinheil's map, in the twelfth hour of right ascension, when



he detected this planet as an object of the ninth or tenth magnitude. Owing to cloudy weather he was unable to confirm his discovery till the 14th, but on that day his observations showed a sensible change of position, and that the suspected object formed one of the group of planetoids.

The magnitude of Hygeia varies from the ninth to the eleventh.

Parthenope (11).—When Hygeia was discovered, Sir John Herschel suggested that the name of Parthenope would have been appropriate, since the ancient name of Naples was derived from that nymph; M. de Gasparis, therefore, used every exertion to carry out Sir John Herschel's proposition, and was successful on the 11th of May, 1850, thus realising, as he states, a "Parthenope" in the heavens. From its alteration of position, the planetary nature of the object was soon ascertained.

At the time of discovery, Parthenope shone as a star of the ninth magnitude; in unfavourable seasons, its lustre is little brighter than the twelfth.

Victoria (12).—On the 13th of September, 1850, Mr. Hind noticed a star of the eighth magnitude, with a bluish light. From its appearance, his suspicions were aroused that the object was another planet. It was situated near a small star which had been frequently noticed, without having for a companion such a bright object. In less than an hour, the brighter star had retrograded two seconds of time; its identity as a planet was therefore established.

Though Victoria, when first noticed, appeared of the eighth magnitude, yet at some subsequent oppositions, no instrument unless of superior penetrating power was able to distinguish it. Its mean opposition magnitude is, however, rather brighter than the tenth.

The name of Victoria was formerly objected to by American astronomers on the ground of its departure from the rule of selecting female classical divinities; and also from an idea that it was not desirable to encourage names given in honour of living individuals. For some time, therefore, this planet was known in America as *Clio.* For the sake of uniformity, the name of Victoria is now universally adopted, that of Clio being given to a subsequent discovery.

Egeria (13).—This planet was discovered by M. de Gasparis, at Naples, on the 2nd of November, 1850, resulting from a series of observations in zones of declination undertaken for the express purpose of discovering these minute bodies. The motion of the planet soon satisfied the observer that the suspected object was a planet.

Egeria at its first appearance was about the ninth magnitude; it descends occasionally as low as the twelfth.

Irene (14).—On the night of the 19th of May, 1851, during an

examination of the heavens near a star which had been previously noticed, Mr. Hind remarked an object near it of similar magnitude, and from his knowledge of that part of the heavens, he felt convinced that the object was a new planet. Mr. Hind considers, that, so far as he is concerned, the discovery is due to his familiarity with telescopic stars gained in his repeated examinations for minute objects. Observations soon established this object as a planet, its motion being evident in a short interval of time.

Mr. Hind remarks: "On the night of the discovery it was noticed that there was a decided contrast between the light of the star and that of the planet; the former was very white and vivid, while the latter had a dull bluish tinge. The planet also appeared to be enveloped in an extremely faint nebulous atmosphere, the existence of which has been confirmed on several subsequent occasions, though it requires a perfectly clear night, and great attention, to render it very evident."

The planet occasionally shines as a star of the ninth magnitude; its minimum is the twelfth.

M. de Gasparis of Naples discovered Irene four days after Mr. Hind, an instance how closely the heavens were scrutinised. Other independent discoveries of planets have taken place, as well as on this occasion, which will appear hereafter.

Eunomia (15).—This planet was discovered at Naples, by M. de Gasparis, on the 29th of July, 1851, shining as a star of the ninth magnitude.

Eunomia, occasionally, is tolerably bright, being of the eighth magnitude; it, however, in other parts of its orbit becomes almost invisible. During the opposition of this planet in the summer of 1860, its magnitude was unusually great, appearing of nearly equal brilliancy to Vesta.

Psyche (16).—During the evening of the 17th of March, 1852, M. de Gasparis discovered this planet, which at the time was situated near Regulus, with which it was compared, and its planetary motion detected. As Irene was first discovered by Mr. Hind, and in four days after by M. de Gasparis, so in this instance, if the Naples astronomer failed to notice Psyche, Mr. Hind would most probably have been soon in a position to claim the merit of its discovery. On the 18th of January, during a final revision of an ecliptical chart before placing it in the engraver's hands, Mr. Hind entered an object shining as a star of the eleventh magnitude. Cloudy weather prevented any re-examination of this object until a proof of the engraving arrived on the 18th of March. On the evening of that day, on comparing the chart with the heavens, the star was not to be found. Its planetary character was at once evident. A vigorous search after the missing object was resolved

on, but before a favourable opportunity arrived, notice was given of its discovery by M. de Gasparis. Professor Gauss has shown that the estimated place of the planet on January 29, agrees well with the elements deduced from the observations. Its planetary nature, however, was not known to Mr. Hind till the night following the actual discovery at Naples.

The mean opposition magnitude of Psyche is about the tenth.

Thetis (17).—Dr. R. Luther, of the observatory of Bilk, near Dusseldorf, discovered this planet on the 17th of April, 1852, which soon proved itself to be one of the remarkable group of minute planets. It shines, generally, when in its most favourable position, as a star of the ninth magnitude.

Melpomene (18).—This planet was discovered by Mr. Hind during the night of the 24th of June, 1852. It appeared with a brilliancy equal to a star of the ninth magnitude, in a position where no known member of these bodies could be situated. Observations with a micrometer soon indicated a sensible change of position.

Mr. Hind has frequently remarked a strong yellowish colour about the light of Melpomene, contrasting in a visible manner the appearance of the planet with the small stars in the same field of view of the telescope.

When in favourable parts of its orbit, this planet shines similarly to a star of the eighth or ninth magnitude.

Fortuna (19).—This planet is another of Mr. Hind's discoveries. On the 22nd of August, 1852, he noticed an object of the ninth magnitude, when, after comparing it with another star, the motion westward was appreciable in about twenty minutes.

Fortuna shines usually at opposition as an object of the ninth magnitude.

Massilia (20).—On the 19th of September, 1852, a new planet was discovered at Naples by M. de Gasparis, shining as a star of the ninth magnitude. This planet was also independently discovered by M. Chacornac at Marseilles, on the 20th of September, while forming a chart of the positions of stars near the ecliptic. The honour of being the first discoverer, however, is due to M. De Gasparis.

The brilliancy of Massilia varies from the eighth to the eleventh magnitude, according to its position in its orbit.

Lutetia (21).—The planet Lutetia was discovered on the 15th of November, 1852, by Mr. Hermann Goldschmidt, an amateur astronomer at Paris. It appeared of about the ninth magnitude, but soon became much fainter. Its mean opposition brightness is equal to stars of the tenth magnitude.

The discovery of this planet by M. Goldschmidt was made with

a small ordinary telescope, placed in the balcony of his apartment in the Rue du Seine, Faubourg St. Germain.

The zeal and devotion of this astronomer have been rewarded by the discovery of no less than twelve of these interesting members of the solar system.

Calliope (22).—In the night of the 16th of November, 1852, while Mr. Hind was comparing the heavens with one of his ecliptical star-maps, he noticed an object which was not entered on the chart. Its planetary nature was soon identified by comparing its motion with the neighbouring stars. The maximum brightness of Calliope is similar to a star of the ninth magnitude, though in some parts of its orbit the intensity of light is so small as to render the planet visible only with telescopes of a superior degree of penetrating power.

Thalia (23).—On the evening of the 15th of December, 1852, Mr. Hind detected another planet, which received the name of Thalia. Like Calliope, this planet was discovered by means of the ecliptical star-maps, formed under his own direction. When first seen, it shone scarcely brighter than stars of the tenth or eleventh magnitude; a degree of faintness which forbids the use of ordinary telescopes in attempting its observation.

The mean opposition magnitude of Thalia is about the eleventh; its minimum brightness is no greater than the thirteenth or fourteenth magnitude.

Themis (24).—The planet Themis was discovered at Naples, on the 6th of April, 1853, by M. de Gasparis. Whilst searching for a small star of the eleventh magnitude which had previously been observed but which had become invisible, that astronomer took notice of a small object of the twelfth magnitude which was new to him, the proper motion of which was soon recognised on comparison with a neighbouring star. Themis shone as an extremely minute object: the greater merit, therefore, is due to the indefatigable observer through whose exertions the astronomical world were made acquainted with its existence.

No instrument, except of a superior class, can be expected to perceive this minute body, its mean opposition magnitude being about the twelfth.

Phocea (25).—While M. de Gasparis was engaged in the consideration of Themis, M. Chacornac was equally engaged on another new member of the planetoids, which he discovered also on the 6th of April, 1853, at Marseilles. It received the name of Phocea. When first seen it appeared as a star of the ninth magnitude, having a bluish tint. On comparison with another star its motion was detected.

The apparent magnitude of Phocea is variable; it changes from

the ninth, when the planet is most favourably situated for observation, to the twelfth, when its position in its orbit places it at its greatest distance from the earth.

Proserpine (26).—The planet Proserpine was discovered on the 5th of May, 1853, at Bilk, by Dr. Luther. When detected, it appeared exceedingly faint, being no brighter than a star of the tenth or eleventh magnitude.

At opposition, its mean intensity of light equals an object of about the tenth magnitude.

Euterpe (27).—The planet Euterpe was found on the evening of the 8th of November, 1853, by Mr. Hind, while he was comparing one of his ecliptical maps with the heavens. It was shining as a star of the ninth magnitude, and was shortly proved by its motion to be a planet.

The magnitude of Euterpe is generally about the tenth when in opposition.

Bellona (28).—The planet Bellona was discovered by Dr. Luther, at Bilk, on the 1st of March, 1854. Its mean amount of brilliancy at opposition is about equal to stars of the tenth magnitude.

Amphitrite (29).—On the 1st of March, 1854, and only about two hours later than the discovery of Bellona, Mr. Marth detected the planet Amphitrite, at the Regent's Park Observatory. It was also independently found by Mr. Pogson at Oxford, on the 2nd of March, and by M. Chacornac at Marseilles, on the 3rd of March. On its first appearance, Amphitrite shone as a star of the tenth or eleventh magnitude. Its brilliancy is, however, occasionally much greater, the maximum being about the ninth magnitude.

Urania (30). The planet Urania was discovered by Mr. Hind about midnight on the 22nd of July, 1854, shining as an object of the ninth or tenth magnitude. Urania is, however, extremely faint in unfavourable positions for observation.

The number of planetoids discovered by Mr. Hind thus amounts to ten, Urania being the last found by that indefatigable astronomer. The instrument used in his researches is an equatorially-mounted achromatic telescope, having an object-glass of seven inches aperture, and about eleven feet focal length.

Euphrosyne (31).—The planet Euphrosyne was discovered on the 1st of September, 1854, at Washington, America, by Mr. Ferguson. Its position on the night of its discovery was rather singular. Mr. Ferguson was in search of Egeria, which he observed in company with another object which was so close to Egeria as to create some uncertainty in his mind which of the two was the planet. Another night's observation, however, decided the planetary nature of both objects, one of which was Egeria and the other was found to be a new planet.

With the exception of Pallas, the obliquity of the orbit of Euphrosyne is greater than any of the remaining planetoids, amounting to 26° 27′.

The magnitude of this planet at mean opposition is about the eleventh.

Pomona (32).—The planet Pomona was detected on the 26th of October, 1854, at Paris, by M. Goldschmidt on comparing an ecliptical star-map with the heavens. It appeared as a star of the eleventh magnitude, which is about its mean brilliancy at opposition.

Polyhymnia (33).—This planet was also discovered at Paris. On the night of the 28th of October, 1854, it was found by M. Chacornac, of the Imperial Observatory.

Of all the known planets, Polyhymnia is remarkable for the large excentricity which is exhibited by the elements of its orbit; the difference between the perihelion and aphelion distances amounting to a diameter of the earth's orbit.

The intensity of light shown by Polyhymnia varies considerably; its magnitude changing from the ninth to the thirteenth.

Circe (34).—The planet Circe was discovered at the Imperial Observatory, Paris, on the 6th of April, 1855, by M. Chacornac. By comparison with the star 25,438 of the catalogue of Lalande, its identity as a planet was confirmed.

The magnitude of Circe is extremely faint, its mean opposition brightness being equal to a star of the eleventh or twelfth magnitude.

Leucothea (35).—Dr. Luther discovered the planet Leucothea on the night of the 19th of April, 1855, shining as a star of the eleventh magnitude, which is about the maximum brightness. This planet is generally of such extreme faintness, as to make it an object of difficulty even with telescopes of the greatest optical power.

Atalanta (36).—On the 5th of October, 1855, M. Goldschmidt discovered the planet Atalanta, at Paris; it resembled a star of the eleventh or twelfth magnitude, which is about its brightness at mean opposition.

Fides (37).—The planet Fides was detected on the evening of the 5th of October, 1855, at Bilk, by Dr. Luther, being the second planetary discovery on the same evening.

The magnitude of Fides at mean opposition is about the tenth.

Leda (38).—M. Chacornac discovered the planet Leda on the 12th of January, 1856, at Paris, shining as a star of the tenth magnitude.

The mean opposition magnitude of Leda is about the eleventh.

Lætitia (39).—The planet Lætitia was detected at Paris also by M. Chacornac, on the 8th of February, 1856. On comparing the

suspected object with 21,963 of Lalande's catalogue, its motion was soon perceived.

The appearance of Lætitia varies considerably in magnitude; when at the greatest it shines as a star of the ninth, and at its minimum brilliancy, about the twelfth magnitude.

Harmonia (40).—This planet was discovered by M. Goldschmidt on the evening of the 31st of March, 1856, at Paris, shining as a star of the ninth or tenth magnitude.

Harmonia is generally of average brightness, its mean opposition magnitude scarcely exceeding the ninth.

Daphne (41).—The planet Daphne was also discovered by M. Goldschmidt. It was found on the 22nd of May, 1856, at Paris. Owing to the lateness of the discovery, which was made when Daphne had considerably passed opposition, and to the increasing daylight, very few observations were made of this planet, too few, in fact, for the determination of reliable elements of its orbit. In consequence of this uncertainty, Daphne was not seen during several years. A special search was, however, made at one of its expected oppositions, when Dr. Luther found it on the 31st of August, 1862.

Isis (42).—The planet Isis was discovered at the Radcliffe Observatory, Oxford, on the 23rd of May, 1856, by Mr. Pogson. It appeared as a star of the tenth magnitude, which is about its brightness at mean opposition.

Ariadne (43).—Mr. Pogson, while comparing one of his manuscript charts with the heavens at the Radcliffe Observatory, Oxford, on the 15th of April, 1857, detected an object which, on comparing with a neighbouring star, proved to be another planet. It received the name of Ariadne. Its brightness at mean opposition is similar to a star of the tenth magnitude.

Nysa (44).—This planet was found by M. Goldschmidt on the 27th of May, 1857, resembling a star of the tenth or eleventh magnitude. In favourable positions of the planet in its orbit, it is considerably brighter.

Eugenia (45).—The planet Eugenia was discovered also by M. Goldschmidt. On the 28th of June, 1857, while scrutinising the heavens, he saw an object which proved to be a planet. The intensity of light of Eugenia is very faint, and a good telescope is required to make satisfactory observations.

Hestia (46).—The planet Hestia was detected on the 16th of August, 1857, at Oxford, by Mr. Pogson, with the assistance of a 5-feet telescope, generously lent by Dr. Lee of Hartwell, for his private use, placed in the garden attached to his residence. Hestia is one of the faintest planets of the group, its mean opposition magnitude being no greater than the twelfth or thirteenth. Occasionally the magnitude is so very minute, that it is scarcely within the limits of vision even with first class telescopes.

Aglaia (47).—Dr. Luther discovered this planet on the 15th of September, 1857, at Bilk. The faintness of Aglaia prevents it from being frequently observed. Its magnitude is about the eleventh or twelfth at mean opposition.

Doris (48) and *Pales* (49).—These two planets were discovered on the same night, on the 19th of September, 1857, by M. Goldschmidt, at Paris. Whilst that astronomer was engaged upon the identification of the planetary nature of Doris, he necessarily neglected attending to a star which had vanished in the vicinity of κ Aquarii; later in the evening, however, his attention was directed to an object which soon exhibited a change in its relative position with respect to the neighbouring stars, and consequently was proved to be a second planet, which afterwards received the name of Pales. At the time of discovery, the two planets were separated only by about three minutes of right ascension, and one degree of declination. The singular fortune of a double discovery on the same night has not fallen to any other discoverer.

These planets are both rather minute at mean opposition, Doris being of the eleventh, and Pales of the tenth or eleventh magnitude.

Virginia (50).—The planet Virginia was first noticed on the 4th of October, 1857, at Washington, U. S., by Mr. Ferguson. An independent discovery was made at Bilk, by Dr. Luther, on the 19th of October, before intelligence had reached Europe of its previous detection. This planet is also exceedingly minute, its mean opposition magnitude being between the twelfth and thirteenth, while in other positions of its orbit, where it is more unfavourably situated, it shines as a star of the fourteenth or fifteenth magnitude.

Nemausa (51).—The planet Nemausa was found by M. Laurent, at the Observatory at Nismes, in the south of France, on the 22nd of January, 1858. Its intensity of light is not great.

Europa (52).—M. Goldschmidt was the discoverer of this planet, on the 6th of February, 1858, at Paris. Its mean opposition magnitude is estimated as being equal to about the tenth.

Calypso (53).—This planet was detected at Bilk, by Dr. Luther, on the 4th of April, 1858. When first noticed it resembled a star of the eleventh magnitude, which doubtless is the appearance by which it will be generally distinguished.

Alexandra (54).—The planet Alexandra was discovered on the 10th of September, 1858, by M. Goldschmidt, at Paris. The magnitude of this planet must be classed amongst those of the faintest, requiring a good telescope for its detection.

Pandora (55).—This planet was discovered at the Dudley Observatory, Albany, United States, by Mr. Searle, on the night of the 10th of September, 1858, only a few hours later than the

discovery of Alexandra. Pandora was discovered by a very ordinary telescope, called a comet-seeker, and though suspected as a new planet on the 10th, its planetary motion was not confirmed till the 11th of September.

The magnitude of Pandora must have considerably decreased soon after its discovery, for in the latter part of November, 1858, several observations were made with the transit-circle at the Royal Observatory, Greenwich, when the observer remarked that it was of the last degree of faintness. At that time, however, the planet was not in a favourable part of its orbit for observation.

Melete (56).—The discovery of this object, and its confirmation as a new member of the solar system, was of an unusually interesting character. It was first discovered on the 9th of September, 1857, by M. Goldschmidt, at Paris, whilst searching for the planet Daphne. When the latter planet was detected in 1856, it had passed opposition for a considerable period, so that only four observations, at no great interval of time, could be made before it was lost in the rays of the sun. An approximate ephemeris was, however, computed from these observations for the succeeding opposition; of this ephemeris M. Goldschmidt availed himself, and by its assistance, he considered he should be enabled to rediscover the lost planet. After searching with considerable devotion, he discovered an object which, by its motion in comparison with other stars, proved to be a planet. This object was, therefore, supposed to be Daphne, not only by M. Goldschmidt, but by the astronomical world in general, and several observations were secured at different observatories during the period of its visibility. Elements of the orbit of the new planet were soon computed, and though their agreement was not perfect with those obtained from the few observations of Daphne when first discovered, yet no suspicion existed on the subject. It appeared, however, by the investigations of M. Ernest Schubert, who in the year 1858 had been engaged to compute an ephemeris for Daphne, for the American Nautical Almanac, that it was found impossible to reconcile the results of an orbit computed from the observations of 1857 with the observations made at the original discovery of Daphne in the preceding year. M. Schubert, therefore, came to the conclusion that the object discovered by M. Goldschmidt in 1857, September 9, was in reality, *not* Daphne, but a new member of the group of planetoids.

By the computer's skill, therefore, Melete was first added to the list of minor planets. In the order of discovery it is placed according to the date of its identification as a new planet by M. Schubert, in 1858, though its actual detection took place between the dates of the discoveries of Hestia and Aglaia.

Mnemosyne (57).—The planet Mnemosyne was discovered on the

22nd of September by Dr. R. Luther, of Bilk. It shines in favourable positions as a star of the tenth magnitude.

Concordia (58).—The discovery of Concordia is also due to Dr. Luther. While scrutinizing the heavens on the 24th of March, 1860, he perceived that a very minute object of the eleventh magnitude had an evident planetary motion. By comparing it with a neighbouring star, he was soon able to announce it to the world as the fifty-eighth member of the group of planetoids. Concordia has always been extremely faint, and has not been observed with the meridional instrument of Greenwich to any great extent.

Olympia (59).—Before the discovery of this planet it seemed apparent that the observing activity of the astronomers had nearly exhausted this planetary mine in space; for in the preceding two years Mnemosyne and Concordia only were found. On the night of the 12th of September, 1860, M. Chacornac, however, detected Olympia in the constellation Cetus, shining as a star of the ninth or tenth magnitude. This announcement was followed by three others within the short period of a month. For some time after this, discovery after discovery was made at short intervals, which taxed to the extreme all the energies of the astronomer, both official and amateur, in following the planets in their orbits, and in preparing the necessary ephemerides for their identification. Olympia is also known by the name of *Elpis*, particularly in Germany.

Echo (60).—This planet was found by Mr. Ferguson, at the Naval Observatory, Washington, U. S., on the night of the 15th of September, 1860. It was first noted on the 14th as a star not on Chacornac's charts, but on the 15th its motion among the stars proved at once its planetary nature. Its estimated magnitude was the eleventh.

Danaë (61).—This planet was first seen by M. Goldschmidt on the 9th of September, 1860, at Chatillon-sous-Bagneux, France. It was situated in the constellation Aquarius, near the star Lalande 44,384. M. Goldschmidt suffered from illness in the interval between the 9th and 19th of September, which prevented him from decidedly fixing the planetary nature of Danaë before the latter date. On this day, however, he was enabled to make complete observations of the planet both in right ascension and declination, and to announce it as a new planet. It shone as a star of the eleventh magnitude.

Erato (62).—The discovery of Erato by MM. Förster and Lesser at Berlin was unusually interesting. On the first receipt of the intelligence of M. Chacornac's detection of Olympia, MM. Förster and Lesser, of the Berlin Observatory, made an extensive series of observations of the supposed new object with the equatorial of that observatory. After the usual reduction of the observations,

the right ascensions and declinations were published in October in the *Astronomische Nachrichten*, as belonging to Chacornac's planet. On comparing these results with those of other observers, MM. Förster and Lesser found a total disagreement between them. These astronomers were at once convinced that they had been, from September 14 to October 10, unconsciously observing a distinct planet. The estimated magnitude of Erato at the time of discovery was the eleventh. If we fix the date of the first detection of Erato for September 14, no less than four minor planets were added to the known members of the solar system in a week; an event unprecedented in the history of planetary discovery.

Ausonia (63).—The planet Ausonia was first seen by M. de Gasparis, at Naples, on the night of the 10th of February, 1861, shining with the brilliancy of a star of the tenth magnitude. Its motion in the heavens was detected by comparing it with Weisse xi. 120.

Angelina (64).—A telegraphic despatch from Marseilles appeared in the Bulletin of M. Le Verrier, announcing the discovery of a new planet on the 4th of March, 1861, by M. Tempel. Its magnitude was estimated as the tenth. The name Angelina refers to Zach's astronomical station at Notre Dame des Anges, near Marseilles.

Cybele (65).—The discovery of Cybele is also due to M. Tempel, of Marseilles. When first noticed, on the 8th of March, 1861, it was in the immediate neighbourhood of Angelina. The planet's magnitude was between the tenth and eleventh, and the star of comparison was Lalande 22,905. Cybele is occasionally called *Maximiliana.*

Maia (66).—The planet Maia was discovered at the observatory of Harvard College, Cambridge, U. S., by Mr. H. P. Tuttle, on the night of the 9th of April, 1861. Its planetary nature was identified by comparing it with No. 76 of the Harvard zones. The magnitude of Maia when first seen was very small, being no greater than the thirteenth.

Asia (67).—This planet was found, like each of those previously discovered by Mr. Pogson, by means of his own manuscript charts, and not by mere gleaning in celestial fields previously mapped out by other astronomers. Mr. Pogson first observed Asia at Madras, on the 17th of April, 1861, it being at that time between the eleventh and twelfth magnitudes. The name of Asia was selected as a fitting record of the first planetary discovery made in that quarter of the globe.

Leto (68).—Dr. R. Luther found Leto at the Bilk Observatory, near midnight on the 29th of April, 1861, by comparing the new object with a known star catalogued by M. Rümker.

Hesperia (69).—Hesperia was first observed by M. Schiaparelli, at Milan, also on the 29th of April, 1861. At the time of discovery the planet was only 9′ distant from Ausonia, for which it was at first taken.

Panopea (70).—M. Goldschmidt detected this planet on the 5th of May, 1861, at Fontenay-aux-Roses, near Paris. The magnitude was between the tenth and eleventh. This is the fourteenth and last planet discovered by this indefatigable observer. The optical means in the possession of the late M. Goldschmidt were never great, his discoveries having been made with telescopes whose object-glasses were only of 2, $2\frac{2}{3}$, or 4 inches aperture. It is truly astonishing that an amateur astronomer, an artist by profession, should have been able to detect so large a number of a class of objects, most of which, from their extreme faintness, have taxed to the utmost official astronomers to observe, even with large fixed telescopes. The Rev. R. Main, Radcliffe Observer at Oxford, has remarked that "none of M. Goldschmidt's telescopes were mounted equatorially, but that, in the greater number of instances, they were pointed out of a window which did not command the whole of the sky; and I leave you to form your own opinion of that fertility of invention and resource, that steady determination to conquer apparently insurmountable difficulties, the untiring industry, and the never-failing zeal, which realised such splendid results with such inadequate means."

Niobe (71).—Dr. R. Luther discovered Niobe, at Bilk, on the evening of the 13th of August, 1861. He estimated the magnitude to be about the eleventh.

Feronia (72).—This object was first observed by Dr. C. H. F. Peters, of Hamilton College, Clinton, U. S., on the 29th of May, 1861, for the planet Maia; but it was subsequently found by Mr. Safford, of Cambridge, U. S., to be really another planet. Professor G. P. Bond has communicated the following interesting account of Mr. Safford's identification of Feronia. "Having had occasion to refer to the positions of Maia obtained by Dr. Peters at Hamilton College, Mr. Safford was surprised to find that only three of the series, namely, the places for 1861, May 9, 11, and 12, could be reconciled with the Cambridge (U. S.) observations. A reference to Mr. Hall's ephemeris of Maia showed that it represented the Cambridge observations of Maia from April 9 to May 27, nine in number, and also the first three of those of Dr. Peters, but that it did not represent the later observations of Dr. Peters. It was at once conjectured that, in the interval between May 12 and May 29, when clouds and moonlight intervened to prevent a close following of Maia, which was only of the 13th magnitude, Dr. Peters had lost its trace, and on resuming his observations had fallen on a new planet."

Clytie (73).—This planet was detected by Mr. Tuttle, at Cambridge, U. S., on the morning of April 8 (3^h A. M.), 1862. It was of the twelfth magnitude.

Galatea (74).—Galatea was first seen by M. Tempel, at Marseilles, on the evening of the 29th of August, 1862, the planet being of the eleventh magnitude.

Eurydice (75).—Dr. C. H. F. Peters discovered this planet on the 22nd of September, 1862, at Clinton, U. S., shining as a star of the eleventh magnitude.

Freia (76).—The planet Freia was first observed by Professor D'Arrest, at Copenhagen, on the 21st of October, 1862. It was of the twelfth magnitude.

Frigga (77).—Discovered by Dr. C. H. F. Peters, on the 12th of November, 1862, at Clinton, U. S.

Diana (78).—The planet Diana was found by Dr. R. Luther, who first saw it on the 15th of March, 1863. Its estimated magnitude was the tenth.

Eurynome (79).—Eurynome was discovered by Mr. Watson, at Ann Arbor, Michigan, U. S., on the 14th of September, 1863, shining as a star of the tenth magnitude. M. Tempel, of Marseilles, made an independent discovery of this planet on October 13.

Sappho (80).—The planet Sappho was found at Madras, by Mr. Pogson, on the 3rd of May, 1864. Its estimated magnitude was the eleventh.

Terpsichore (81).—This is the fourth planet discovered by M. Tempel, of Marseilles. It was first noticed on the 30th of September, 1864, the magnitude being the tenth.

Alcmene (82).—Discovered by Dr. R. Luther, on the 27th of November, 1864, at about 9½ h. in the evening. Its estimated magnitude was the eleventh.

Beatrix (83). This minor planet was first observed by M. de Gasparis, at Naples, on the 26th of April, 1865. Its planetary nature was detected by comparisons of its position with that of Weisse xiii. 13. The planet shone equal to a star of the tenth or eleventh magnitude.

Clio (84).—This planet is another of Dr. R. Luther's discoveries. It was first observed on the 25th of August, 1865, shining as a star of the tenth magnitude.

Io (85).—Discovered by Dr. C. H. F. Peters, at Clinton, U. S., on the 19th of September, 1865. Its estimated magnitude was the tenth.

Semele (86).—The planet Semele was detected at Berlin, by Dr Tietjen, on the 6th of January, 1866, while searching for Io. It was a very faint object, its magnitude being the twelfth.

Sylvia (87).—Discovered by Mr. Pogson, at Madras, on the 16th of May, 1866.

Thisbe (88).—Discovered by Dr. C. H. F. Peters, at Clinton, U. S., on the 15th of June, 1866.

(89).—Discovered by M. Stéphan, at Marseilles, on the 6th of August, 1866.

Antiope (90).—This is the *fifteenth* planet discovered by Dr. R. Luther, who now stands at the head of planet-discoverers, having exceeded the number of the late M. Goldschmidt by one. This planet was first observed on the 1st of October, 1866.

(91).—Discovered by M. Stéphan on Nov. 5 (2^h A.M.), 1866.

373. **Decrease in brightness of successive groups of planetoids.**—It is very probable that nearly all the brighter members of this remarkable group of minor planets have now been discovered, and that those remaining will require the best optical means for their detection. Notwithstanding, however, the extreme minuteness of these objects, and the excessive delicacy of observation required, there does not appear to be any falling off in the zeal of those observers who have particularly devoted themselves to this class of astronomical labour. Year after year adds new names to the known members of our solar system. As might have been expected, the brightest members were generally found first, the four discovered in the beginning of this century having, at opposition, magnitudes varying from the sixth to the eighth. As an illustration of the gradual decrease in brightness of successive groups of these small bodies, we have collected their mean opposition magnitudes, and formed them into groups in order of discovery. The result is exhibited in the following table:—

Group.	Planet's Number.	Mean Opposition Magnitude of Group.
1	1 to 4	7·5
2	5 to 10	9·4
3	11 to 20	9·6
4	21 to 30	10·1
5	31 to 50	11·0
6	51 to 70	11·3
7	71 to 90	11·5

Again, we have made a similar operation with regard to the planets' mean distances from the sun, and have found that a very strong tendency is shown in the same direction. Taking the first twenty planets in order of discovery, their mean distance from the sun, that of the earth being unity, is 2·52; in the second twenty it is 2·67; in the third, 2·68; and in the fourth, 2·71. These numbers would seem to indicate that the day of finding these minute objects with very small telescopes is gone, and that observers in future will scarcely hope to succeed in adding to the list, unless

they have at command instruments furnished with object-glasses of considerable aperture.

374. **Duplicate discoveries.**—We have mentioned incidentally that several of the planets in the preceding list have been discovered by two or more observers independently. This gives a good practical illustration of the careful methods adopted in searching for these bodies. For example, Irene was first seen by Mr. Hind on the 19th of May, 1851, and by M. de Gasparis on the 23rd of May. Massilia was first observed by M. de Gasparis on the 19th of September, 1852, and by M. Chacornac on the 20th of September; whilst Amphitrite was discovered separately by no less than three observers; by Mr. Marth on the 1st of March, 1854, by Mr. Pogson on the 2nd of March, and by M. Chacornac on the 3rd of March. One or two others were also found independently by two observers, but the interval of time between the two discoveries was longer than those mentioned above; for instance, Virginia was discovered by Dr. R. Luther on the 19th of October, 1857, before the intelligence of its previous discovery on the 4th of October was received from America; and Eurynome was similarly observed by M. Tempel before information had reached him of its discovery by Mr. Watson nearly a month previously.

375. **Arrangement for continuous observations.**—When the number of minor planets was small, no difficulty was experienced in fixed observatories in obtaining a sufficient number of observations of each object for the determination and correction of the elements of its orbit. When the number, however, had increased to an extent which was found to interfere seriously with the ordinary astronomical work, the directors of the principal observatories agreed that some mutual arrangement ought to be made for their continuous observation. At first, a selection of eight was made as the special charge of each establishment. At the Royal Observatory, Greenwich, all which were provided with a tolerably correct ephemeris were assiduously observed. This labour eventually became so great, that a mutual understanding, or convention, took place between the Astronomer Royal, on the part of the Royal Observatory, and M. Le Verrier, on that of the Imperial Observatory of Paris, to divide the observations of minor planets between the two national observatories. This convention was drawn up in the year 1863, by which it was agreed that all the minor planets which passed the meridian between 10 P.M. and 1 A.M. in the first half of the lunation should be observed at Greenwich, and those which culminated between the same hours in the second half of the lunation should be observed at Paris. This arrangement has been continued with great success, all the observations and results being published in the *Greenwich*

Astronomical Observations, and also in the *Annales de l'Observatoire Impérial de Paris.* The minor planets are also observed with great regularity at most of the principal foreign observatories, particularly at Washington, Leyden, Berlin, &c.

376. **Zeal of the discoverers.**—A glance at the names of the astronomers who have distinguished themselves in the discovery of the minor planets, will give some idea of their unbounded energy and zeal in the prosecution of their labours. It is difficult to realize in one's mind the constant examination of the heavens, or the hours of anxious watching, required, before one of these small bodies can be identified as a planet. Many of our most fruitful discoverers have only succeeded after mapping down every minute star in certain limited zones in the heavens. Even in this work they may have spent hours on every clear night for many months before receiving the reward of their difficult and harassing employment. For our knowledge of the existence of these small items of our solar system, we are indebted to Dr. R. Luther for no less than *fifteen*; to M. Goldschmidt, *fourteen*; to Mr. Hind, *ten*; to M. de Gasparis, *nine*; to M. Chacornac and Mr. Pogson, *six* each; to Dr. C. H. F. Peters, *five*; to M. Tempel, *four*; to Mr. Ferguson, *three*; to MM. Olbers, Hencke, Tuttle, and Stéphan, *two* each; to MM. Piazzi, Harding, Graham, Marth, Laurent, Searle, Schiaparelli, D'Arrest, Watson, and Tietjen, *one* each; and finally to MM. Förster and Lesser, *one* jointly.

377. **The remarkable accordance of the planetoids with Dr. Olbers' hypothesis.**—The orbits of the planetoids are all comprised between the mean distances 2·2 and 3·5, that of the earth being 1·0. The magnitudes of all these bodies, with one or two exceptions, are too minute to be ascertained by any means of measurement hitherto discovered, and may be inferred with great probability not to exceed 100 miles in diameter. The largest of the group is probably less than 500 miles in diameter, while those which are considered the most minute are supposed to be only a few miles in diameter. It cannot fail, therefore, to be observed in how remarkable a manner the planetoids generally conform to the conditions involved in the hypothesis of Dr. Olbers.

377 *a*. **Mutual relations between the orbits of the planetoids.**—It cannot, however, be denied that there is much uncertainty in maintaining this theory of Dr. Olbers as the true origin of that ring of small bodies between Mars and Jupiter. The hypothesis of their being shattered fragments of some brilliantly large planet, which might have been the focus of a great catastrophe countless ages ago, may or may not be true; but the researches of modern mathematicians certainly do not appear to justify our receiving it, except only as a possible assumption. Mr. Newcomb,

an American astronomer, has discussed, with great clearness, the mutual relations and secular variations of the orbits of the planetoids, and he considers that Dr. Olbers' celebrated hypothesis has the advantage of apparently accounting for the phenomena, considered in their mere salient aspects, in a very remarkable manner. For if we consider the phenomenon of the *place* of a single large planet being filled by probably hundreds of small ones of different magnitudes, some with large inclinations and excentricities, and whose mean distances differ but slightly, we might naturally expect such a result to arise from the force necessary to break the planet into numerous fragments, each very small in comparison with the original. Mr. Newcomb remarks: "We shall see that when we carry the results of this hypothesis to numerical exactness, the observed phenomena are very far from agreeing with this idea. Moreover, it is difficult, perhaps impossible, to imagine how any known natural cause, or combination of causes, should produce such a result as a shattering of a planet. But since the limits of our knowledge are not necessarily the limits of possibility, this objection is not fatal, and it is difficult to say what weight ought to be assigned for it." In this elaborate investigation, Mr. Newcomb has discussed the possibility of the orbits of all the planetoids having once intersected in a common point, and whether they have ever been materially affected by a resisting medium. He has also computed the relations between the mean distances, excentricities, and inclinations of the orbits; and also between the masses and the velocities with which they must have been projected, if Olbers' hypothesis be true. The conclusion to which Mr. Newcomb has arrived is, that though there are some peculiarities in the mutual relations between the orbits of the planetoids which might favour this hypothesis, yet there are a far greater number of cases which undoubtedly negative the assumption. Taking, however, the break in Bode's law as an argument in support of a shattered planet, there are many astronomers still inclined to regard it as a subject open to speculation.

378. **Force of gravity on the planetoids.**—From the minuteness of their masses, the force of gravity on the surfaces of these bodies must be very inconsiderable, and this would account for a much greater altitude of their atmospheres than is observed on the larger planets, since the same volume of air feebly attracted would dilate into a volume comparatively enormous. Muscular power would be more efficacious on them in the same proportion. Thus a man might spring upwards sixty or eighty perpendicular feet, and return to the ground sustaining no greater shock than would be felt upon the earth in descending from the height of two or three feet. "On such planets," observes Herschel, "giants might exist, and

those enormous animals which on earth require the buoyant power of water to counteract their weight."

CHAPTER XVI.

THE MAJOR PLANETS.

I. JUPITER.

379. **Jovian system.**—Passing across the wide space which lies beyond the range of the planets, which with the earth, revolve as it were under the wing of the sun,—a space which was regarded as an anomalous desert in the planetary regions until contemporary explorers found there what seem to be the ruins of a shattered world,—we arrive at the theatre of other and more stupendous cosmical phenomena. The succession of planets, broken by the absence of one in the place occupied by the planetoids, is resumed, and four orbs are found constructed upon a comparatively Titanic scale, each attended by a splendid system of moons presenting a miniature of the solar system itself, and revolving round the common centre of light, heat, and attraction at distances which almost confound the imagination.

380. **Period.**—The synodic period of Jupiter is ascertained by observation to be about 399 days. Its sidereal period is 4332·6 days, or 11·86 years.

381. **Distance from the sun.**—The mean distance of Jupiter from the sun is about 5⅕ times that of the earth, and since the earth's mean distance is 91½ millions of miles, that of Jupiter must be 475⅓ millions of miles.

The excentricity of Jupiter's orbit being 0·048, this distance is liable to variation, being augmented in aphelion and diminished in perihelion by 23 millions of miles. The greatest distance of the planet from the sun is therefore 498, and the least 453 millions of miles.

The small excentricity of the orbit of this planet, combined with its small inclination to the plane of the ecliptic, is of great importance in its effect in limiting the disturbances consequent upon its mass, which is greater than the aggregate of the masses of all the other planets primary and secondary taken together. If the orbit of Jupiter had an excentricity and inclination as considerable as those of the planet Juno, the perturbations produced by his mass upon the motions of the other bodies of the system, would be twenty-seven times greater than they are with its present small excentricity and inclination.

Fig. 65.

382. **Relative scale of the orbits of Jupiter and the earth.** —The relative magnitudes of the distances of Jupiter and the earth from the sun, and the apparent magnitude of the orbit of the earth as seen from Jupiter, are represented in *fig.* 65, where the planet is at J, the sun at S, and the orbit of the earth E E′ E‴ E″.

The direction of the orbital motions being represented by the arrows, it will be evident that when the earth is at E the planet is in opposition, at E‴ in conjunction, at E′ in quadrature west, and at E″ in quadrature east of the sun.

383. **Its prodigious orbital velocity.** — The velocities with which the planets move through space in their circumsolar courses are on the same prodigious scale as their distances and magnitudes. It is impossible, by the mere numerical expression of these enormous magnitudes and motions, to acquire any tolerably clear or distinct notion of them. A cannon ball moving at the rate of 500 miles an hour would take nearly a century to come from Jupiter to the earth, even when the planet is nearest to us, and a steam-engine moving on a railway at 50 miles an hour would take nine centuries to perform the same trip.

Taking the diameter of Jupiter's orbit at 1000 millions of miles, its circumference is above 3000 millions of miles, which it moves over in 4333 days. The distance it travels is, therefore, about 700,000 miles per day, 30,000 per hour, 500 per minute, and $8\frac{1}{3}$ per second,—a speed sixty times greater than that of a cannon ball.

384. **Jupiter has no sensible phases.** — The mere inspection of the diagram, *fig.* 65, will show that this planet cannot be sensibly gibbous in any position. The position in which the enlightened hemisphere is in view most obliquely is when the earth is at E′ or E″, and the planet consequently in quadrature, and even then the centre of the visible hemisphere is only 11° distant from the centre of the enlightened hemisphere.

385. **Appearance in the firmament at night.** — Since between quadrature and opposition the planet is above the horizon during the greater part of the night, and appears with a full phase, it is thus favourably placed for observation during 6 months in 13 months.

386. **Stations and retrogression.** — From a comparison of the orbital motions and distance of Jupiter and the earth, it appears that the planet is stationary at about two months before and two months after opposition; and since the earth gains upon the planet at the daily rate of 0°·902, the angle it gains in two months or sixty days must be 54°·12. The angular distance of the points of station from opposition, as seen from the sun, is therefore about 54°, which corresponds to an elongation of 114°.

The planet is therefore stationary at about 66° on each side of its opposition.

Its arc of retrogression is a little less than 10°, and the time of describing it varies from 117 to 123 days.

387. **Apparent and real diameters.** — The apparent diameter of Jupiter when in opposition varies from 42″ to 48″, according to the relative positions of the planet and the earth in their elliptic orbits. At its mean opposition distance from the earth its apparent magnitude is 45″. In conjunction the mean apparent diameter is 30″, its value at the mean distance from the earth being 37½″.

According to the most accurate methods, the mean diameter is ascertained to be 84,846 miles. The diameter of Jupiter is therefore 10·70 times that of the earth.

388. **Jupiter a conspicuous object in the firmament — relative splendour of Jupiter and Mars.** — Although the apparent magnitude of Jupiter is less than that of Venus, the former is a more conspicuous and more easily observable object, inasmuch as when in opposition it is in the meridian at midnight, and when its opposition takes place in winter, it passes the meridian at an altitude nearly equal to that which the sun has at the summer solstice. By reason, therefore, of this circumstance, and the complete absence of all solar light, the splendour of the planet is very great, whereas Venus, even at the greatest elongation, descends generally near the horizon before the entire cessation of twilight.

The apparent splendour of a planet depends conjointly on the apparent area of its disk, and the intensity of the illumination of its surface. The area of the disk is proportional to the square of its apparent diameter, and the illumination of the surface depends conjointly on the intensity of the sun's light at the planet, and the reflecting power of the surface. On comparing Mars with Jupiter, we find the apparent splendour of the latter planet much greater than it ought to be, as compared with the former, if the reflecting power of these surfaces were the same, and are consequently compelled to conclude that the surface of Mars is endowed with some physical quality, in virtue of which it absorbs much more of the solar light incident upon it than that of Jupiter does. When the apparent diameter of the latter is twice that of the former, its apparent area is fourfold that of the former. But the intensity of the solar light at Jupiter is at the same time about thirteen times less than at Mars; and if the reflective power of the surfaces were equal, the apparent splendour of Mars would be more than three times that of Jupiter. The reflective power must, therefore, be less in a sufficient proportion to explain the inferior splendour of Mars, unless, indeed, the very improbable supposition be admitted that there may be a source of light in Jupiter independent of solar illumination.

389. **Surface and volume.**—The surface of Jupiter is above 115 times, and its volume about 1233 times, those of the earth.

To produce a globe such as that of Jupiter, it would be necessary to mould into a single globe 1233 globes like that of the earth.

The relative magnitudes of the globes of Jupiter and the earth are represented in *fig.* 66 by J and E.

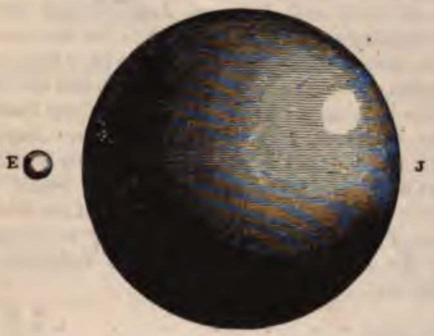


Fig. 66.

390. **Solar light and heat.** — The mean distance of Jupiter from the sun being 5·2 times that of the earth, the apparent diameter of the sun to the inhabitants of that planet will be

Fig. 67.

less than its apparent diameter at the earth in the proportion of 5·2 to 1. The relative apparent magnitudes of the disk of the sun at Jupiter and at the earth are represented in *fig.* 67 at E and J.

The density of solar radiation being in the exact proportion of the apparent superficial magnitudes of the disks, the illuminating and heating powers of the sun will, *ceteris paribus*, be less in the same proportion at Jupiter than at the earth.

As has been already observed, however, this diminished power as well of illumination as of warmth, may be compensated by other physical provisions.

391. **Rotation and direction of the axis.**— Although the lineaments of light and shade on Jupiter's disk are generally subject to variations, which prove them to be, for the most part, atmospheric, nevertheless permanent marks have been occasionally seen, by means of which the diurnal rotation and the direction of the axis have been ascertained within very minute limits of error. The earlier observers, whose instruments were imperfect, and observations consequently inaccurate comparatively with those of more recent date, ascertained nevertheless the period of rotation with a degree of approximation to the results of the most elaborate observations of the present day which is truly surprising, as may appear by the following statement of the estimates of various astronomers: —

	h	m	s
Cassini (1665)	9	56	0
Silvabelle	9	56	0
Schröter (1786)	9	55	33
Airy	9	55	24·6
Mädler (1835)	9	55	26·56

The estimate of Professor Airy is based upon a set of observations made at the Cambridge Observatory. That of Mädler is founded upon a series of observations, commencing on the 3rd of November, 1834, and continued upon every clear night until April, 1835, during which interval the planet made 400 revolutions. These observations were favoured by the presence of two remarkable spots near the equator of the planet, which retained their position unaltered for several months. The period was determined by observing the moments at which the centres of the spots arrived at the middle of the disk.

The direction of the apparent motion of the spots gave the position of the equator, and consequently of the axis, which is inclined to the plane of the planet's orbit at an angle of 3° 6′.

The length of the Jovian day is therefore less than that of the terrestrial day in the ratio of 596 to 1440, or 1 to 2·42.

392. **Jovian years.**— Since the period of Jupiter is 4332·6 terrestrial days, it will consist of 10484·9 Jovian days.*

* The day here computed is the sidereal day, which, in the case of the superior planets, differs from the mean solar day by a quantity so insignificant that it may be neglected in such illustrations as these.

393. **Seasons.**—At the Jovian equinoxes the length of the day in terrestrial time must be $4^h\ 57^m\ 43^s{\cdot}3$. Owing to the very small obliquity of the plane of the planet's equator to that of its orbit, not much exceeding the eighth part of the obliquity of the earth's equator, the difference of the extreme length of the days at midsummer and midwinter, even at high latitudes, must necessarily be small. Thus at

		h	m	s
Lat. 40°.—Longest day	- - - - -	5	6	26
Shortest day	- - - - -	4	49	14
Difference	- - -	0	17	12
Lat 60°.—Longest day	- - - - -	5	15	47
Shortest day	- - - - -	4	39	53
Difference	- - -	0	35	54

The diurnal phenomena at midwinter and midsummer on the earth in latitudes higher than $66\frac{1}{2}°$ are only exhibited on Jupiter within a small circle circumscribing the pole at a distance of $3° 6'$.

The extremes of temperature, so far as they depend on the varying distance of the planet from the sun, being in the proportion of the squares of the aphelion and perihelion distances, are as 5 to 6 nearly.

It appears, therefore, that except in the near neighbourhood of the poles, the vicissitudes of temperature and season to which the surface of this planet is exposed, whether arising from the obliquity of its axis or the excentricity of its orbit, are confined within extremely narrow limits.

394. **Telescopic appearance of Jupiter.**—Of all the bodies of the system, the moon perhaps alone excepted, Jupiter presents to the telescopic observer the most magnificent spectacle. Notwithstanding its vast distance, such is its stupendous magnitude that it is seen under a visual angle nearly twice that of Mars. A telescope of a given power, therefore, shows it with an apparent disk four times greater. It has, consequently, been submitted to examination by the most eminent observers, and its appearances described with great minuteness of detail.

395. **Magnifying powers necessary to show the features of the disk.**—A power of four or five is sufficient to enable the observer to see the planet with a sensible disk; a power of thirty shows the more prominent belts and the oval form of the disk produced by the oblateness of the spheroid; but to be enabled to observe the finer streaks which prevail at greater distances from the planet's equator, it is not only necessary to see the planet under favourable circumstances of position and atmosphere, but to be aided by a well-defining telescope with magnifying powers varying from 200 to 300.

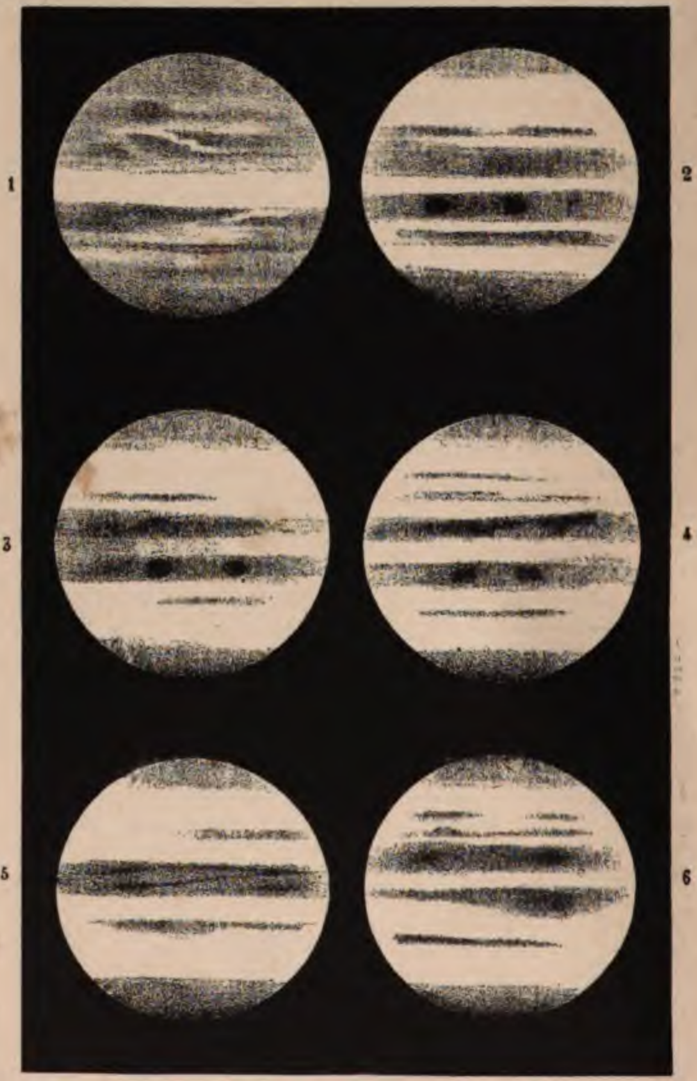
396. **Belts — their arrangement and appearance.** — The planet, when thus viewed, appears to exhibit a disk, the ground of which is a light yellowish colour, brightest near its equator, and melting gradually into a leaden-coloured grey towards the poles, still retaining, nevertheless, somewhat of its yellowish hue. Upon this ground are seen a series of brownish-grey streaks, resembling in their form and arrangement the streaks of clouds which are often observed in the sky on a fine calm evening after sunset. Many observers have noticed the colour of these streaks as having a reddish tinge, a pale brick-red. Their general direction is parallel to the equator of the planet, though sometimes a departure from strict parallelism is observable. They are not all equally conspicuous or distinctly defined. Two are generally strikingly observable, being extended north and south of the planet's equator, separated by a bright yellow zone, being a part of the general ground of the disk. These principal streaks commonly extend around the globe of the planet, being visible without much change of form during an entire revolution of Jupiter. This, however, is not always the case, for it has happened, though rarely, that one of these streaks, at a certain point, was broken sharply off so as to present to the observer, an extremity so well defined and unvarying for a considerable time as to supply the means of ascertaining, with a very close approximation, the time of the planet's rotation. The borders of these principal streaks are sometimes sharp and even, but, sometimes (those especially which are further from the equator) rugged and uneven, throwing out arms and offshoots.

397. **Those near the poles more faint.** — On the parts of the disk more remote from the equator, the streaks are much more faint, narrower, and less regular in their parallelism, and can seldom be distinctly seen, except by practised observers, with good telescopes. With these, however, what appears near the poles, in instruments of inferior power, as a dim shading of a yellowish grey hue, is resolved into a system of fine parallel streaks in close juxtaposition, which becoming closer, in approaching the pole, finally coalesce.

398. **Disappear near the limb.** — In general, all the streaks become less and less distinct towards either the eastern or western limb, disappearing altogether at the limb itself.

399. **Belts not zenographical features, but atmospheric.** — Although these streaks have infinitely greater permanency than the arrangements of the clouds of our atmosphere, and are, as we have seen, even more permanent than is necessary for the exact determination of the planet's rotation, they are nevertheless entirely destitute of that permanence which would characterise Zenographic

[redacted]



JUPITER.

From Telescopic Drawings by MM. Mädler and Herschel.

1. Sept. 25. 1852.
2. Dec. 25, 1854.
3. Dec. 25. 1854.
4. Jan. 2, 1855.
5. Jan. 16, 1856.
6. Jan. 17, 1856.

features, such as are observed, for example, on Mars. The streaks, on the contrary, are subject to slow but evident variations, so that after the lapse of some months the appearance of the disk is totally changed.

400. **Telescopic drawings of Jupiter by Mädler and Herschel.**—These general observations on the appearance of Jupiter's disk will be rendered more clearly intelligible by reference to the telescopic drawings of the planet given in Plate XIX. In *fig.* 1 is given a telescopic view of the disk delineated by Sir John Herschel, as it appeared in the 20-feet reflector at Slough on the 23rd of September, 1832. The other views were made by M. Mädler from observations taken in 1835 and 1836, at the dates indicated on the plate.

401. **Observations and conclusions of Mädler.**—The two black spots represented in *figs.* 2, 3, and 4, were those by which the time of rotation was determined (391). They were first observed by Mädler, on the 3rd of November, 1834. The effect of the rotation of these spots was so apparent that their change of position with relation to the centre of the disk, in the short interval of five minutes, was quite perceivable. A third spot, much more faint than these, was visible at the same time, the distances separating the spots being about 24° of the planet's surface. It was estimated that the diameter of each of the two spots represented in the diagrams was 3680 miles, and the distance between them was sometimes observed to increase at the rate of half a degree, or 330 miles, in a month. The two spots continued to be distinctly visible from the 3rd of November, 1834, when they were first observed, until the 18th of April, 1835; but during this interval the streak on which they were placed, had entirely disappeared. It became gradually fainter in January (see *fig.* 4), and entirely vanished in February; the spots, however, retaining all their distinctness. The planet after April passing towards conjunction, was lost in the light of the sun; and when it reappeared in August, after conjunction, the spots had altogether vanished.

The observations being continued, the drawings, *figs.* 5, and 6, were made from observations on the 16th and 17th of January, 1836, when the entire aspect of the disk was changed. The two figures 5 and 6 represent opposite hemispheres of the planet. The former presents a striking resemblance to the principal belts in the drawing of Sir J. Herschel, *fig.* 1.

It was remarked that the two spots, when carried round by the rotation, became invisible at 55° to 57° from the centre of the disk. This is an effect which would be produced if the spots were openings in the mass of clouds floating in the atmosphere of the planet, and would be explicable in the same manner as is the dis-

appearance of spots on the sun in approaching the edges of the disk. A proper motion with a slow velocity, and in a direction contrary to the rotation of the planet, was observed to affect the spots, and this motion continued with greater uniformity in March and April, after the disappearance of the belt.

It was calculated that the velocity of their proper motion over the surface of the planet, was at the rate of from three to four miles an hour.

Although the two black spots were not observed by Mädler until the first days of November, they had been previously seen and examined by Schwabe, who observed them to undergo several curious changes, in one of which one of them disappeared for a certain interval, its place being occupied by a mass of fine dots. It soon, however, reappeared as before.

From all these circumstances, and many others developed in the course of his extensive and long-continued observations, Mädler considers it highly probable, if not absolutely certain, that the atmosphere of Jupiter is continually charged with vast masses of clouds which completely conceal his surface; that these clouds have a permanence of form, position, and arrangement to which there is nothing analogous in the atmosphere of the earth, and that such permanence may in some degree be explained by the great length and very small variation of the seasons. He thinks it probable that the inhabitants of places in latitudes above 40° never behold the firmament, and those in lower latitudes only on rare occasions.

To these inferences it may be added that the probable cause assigned for the distribution of the masses of clouds in streaks parallel to the equator, is the prevalence of atmospheric currents analogous to the trades, and arising from a like cause, but marked by a constancy, intensity, and regularity exceeding those which prevail on the earth, inasmuch as the diurnal motion of the surface of Jupiter is more rapid than that of the earth in the combined proportion of the velocity of the diurnal rotation and the magnitude of the circumference, that is, as 27 to 1 nearly.

It is also probable that the bright yellowish general ground of Jupiter's disk consists of clouds, which reflect light much more strongly than the most dense masses which are seen illuminated by the sun in our atmosphere; and that the darker streaks and spots observed upon the disk are portions of the atmosphere, either free from clouds and through which the surface of the planet is visible more or less distinctly, or clouds of less density and less reflecting power than those which float over the general atmosphere and form the ground on which the belts and spots are seen.

That the atmosphere has not any very extraordinary height above the surface of the planet, is proved by the sharply defined edge of the disk. If its height bore any considerable proportion to the diameter of the planet, the light towards the edges of the disk would become gradually fainter, and the edges would be nebulous and ill-defined. The reverse is the case.

402. **Spheroidal form of the planet.**—The disk of Jupiter, seen with magnifying powers as low as 30, is evidently oval, the lesser axis of the ellipse coinciding with the axis of rotation, and being perpendicular to the general direction of the belts. This fact supplies a striking confirmation of the results attained in the measurement of the curvature of the earth; and, as in the case of the earth, the degree of oblateness of Jupiter is found to be that which would be produced upon a globe of the same magnitude, having a rotation such as the planet is observed to have.

At the mean distance from the earth, the apparent diameters of the disk are ascertained by exact micrometric measures made at the Royal Observatory, between the years 1840 and 1851, to be—

Equatorial diameter	37″·91
Polar diameter	35 ·66
Mean diameter	36 ·79

The polar diameter is therefore less than the equatorial, in the ratio of 100 to 106·3.

403. **Jupiter's satellites.**—When Galileo directed the first telescope to the examination of Jupiter, he observed four minute stars, which appeared in the line of the equator of the planet He took these at first to be fixed stars, but was soon undeceived. He saw them alternately approach to, and recede from the planet, observed them pass behind it and before it; and oscillate, as it were, to the right and the left of it, to certain limited and equal distances. He soon arrived at the obvious conclusion that these objects were not fixed stars, but that they were bodies which revolved round Jupiter in orbits, at limited distances, and that each successive body included the orbit of the others within it; in short, that they formed a miniature of the solar system, in which, however, Jupiter himself played the part of the sun. As the telescope improved, it became apparent that these bodies were small globes, related to Jupiter in the same manner exactly as the moon is related to the earth; that, in fact, they were a system of four moons, accompanying Jupiter round the sun.

404. **Rapid change and great variety of phases.**—But connected with these appendages there is perhaps nothing more remarkable than the period of their revolutions. That moon which

is nearest to Jupiter, completes its revolution in forty-two hours. In that brief space of time it goes through all its various phases; it is a thin crescent, halved, gibbous, and full. It must be remembered, however, that the day of Jupiter, instead of being twenty-four hours, is less than ten hours. This moon, therefore, has a month equal to a little more than four Jovian days. In each day it passes through one complete quarter; thus, on the first day of the month it passes from the thinnest crescent to the half moon; on the second, from the half moon to the full moon; on the third, from the full moon to the last quarter; and on the fourth returns to conjunction with the sun. So rapid are these changes that they must be actually visible as they proceed.

The apparent motion of this satellite in the firmament of Jupiter is at the rate of more than $8\frac{1}{2}°$ per hour, and is the same as if our moon were to move over a space equal to her own apparent diameter, in less than four minutes. Such an object would serve the purpose of the hand of a stupendous celestial clock.

The second satellite completes its revolution in about eighty-five terrestrial hours, or about eight and a half Jovian days. It passes, therefore, from quarter to quarter in twenty-one hours, or about two Jovian days, its apparent motion in the firmament being at the rate of about $4°{\cdot}25$ per hour, which is as if our moon were to move over a space equal to nine times its own diameter per hour, or over its own diameter in less than seven minutes.

The movements and changes of phase of the other two moons are not so rapid. The third passes through its phases in about 170 hours, or seventeen Jovian days, and its apparent motion is at the rate of about 2° per hour. The fourth and last completes its changes in 400 hours, or forty Jovian days, and its apparent motion is at the rate of little less than 1° per hour, being double the apparent motion of our moon.

Thus the inhabitants of Jupiter have four different months of four, eight, seventeen, and forty Jovian days, respectively.

405. **Elongation of the satellites.**—The appearance which the satellites of Jupiter present when viewed with a telescope of moderate power, is that of minute stars ranged in the direction of a line drawn through the centre of the planet's disk nearly parallel to the direction of the belts, and therefore coinciding with that of the planet's equator. The distances to which they depart on the one side or the other of the planet are so limited, that the whole system is included within the field of any telescope whose magnifying power is not considerable; and their elongations from the centre of the planet can therefore be measured with great precision by means of the wire micrometers.

When the apparent diameter of the planet in opposition is 45″,

the greatest elongations of the satellites from the centre of the planet's disk are as follow:—

I.	135″
II.	215
III.	346
IV.	585

It follows, therefore, that the entire system is comprised within a visual area of about 1200″ in extent, being two-thirds of the apparent diameter of the moon. If, therefore, we conceive the moon's disk to be centrically superposed on that of Jupiter, not only would all the satellites be covered by it, but that which elongates itself most from the planet would not approach nearer to the moon's edge than one-sixth of its apparent diameter.

If all the satellites were at the same time at their greatest elongations, they would, relatively to the apparent diameter of the planet, present the appearance represented in *fig.* 68.

Fig. 68.

406. **Distances from Jupiter.**—The actual distances of the satellites from the centre of the planet may be immediately inferred from a comparison of their greatest elongations with the apparent semi-diameter of the planet. Since, in the case above supposed, the apparent semi-diameter of the planet is 22″·5, the distances will be found expressed with reference to the semi-diameter as the unit, by dividing the greatest elongations expressed in seconds by 22·5. This gives for the distances:—

I.	$\frac{135}{22 \cdot 5} = 6 \cdot 0$
II.	$\frac{215}{22 \cdot 5} = 9 \cdot 6$
III.	$\frac{346}{22 \cdot 5} = 15 \cdot 4$
IV.	$\frac{585}{22 \cdot 5} = 26 \cdot 0$

Relatively to the magnitude of the planet, therefore, the satellites revolve much closer to it than the moon does to the earth. The distance of the moon is nearly 60 semi-diameters of the earth, while the distance of the most remote of Jupiter's moons is not more than 26 semi-diameters, and that of the nearest only six, from his centre.

Owing, however, to the greater dimensions of Jupiter, the

actual distances of the satellites, expressed in miles, are (except that of the first) considerably greater than the distance of the moon from the earth.

407. **Orbits of satellites.**—The orbits of the satellites are ellipses of very small ellipticity, inclined to the plane of Jupiter's orbit at very small angles, as is made apparent by their motions being always very nearly coincident with the plane of the planet's equator, which is inclined to that of its orbit at the small angle of 3° 5′ 30″.

408. **Apparent and real magnitudes.**—The satellites, although reduced by distance to mere lucid points in ordinary telescopes, not only exhibit perceptible disks when observed by instruments of sufficient power, but admit of pretty accurate measurement. At opposition, when the apparent diameter of the planet is 45″, all the satellites subtend angles exceeding 1″, and the third and fourth appear under angles of 1¾″ and 1½″. By observing these apparent diameters with all practicable precision, their real diameters have been ascertained as follows:—

	miles.
I. - - - -	- = 2309.
II. - - - -	- = 2069.
III. - - - -	- = 3378.
IV. - - - -	- = 2891.

It appears, therefore, that with the exception of the second, which is exactly equal in magnitude to the earth's moon, all the others are on a much larger scale; and one of them, the third, is greater than the planet Mercury, while the fourth is very nearly equal to it.

Some observers make the diameters slightly different from those inserted above.

409. **Apparent magnitudes as seen from Jupiter.**—By comparing their real diameters with their distances, the apparent diameters of the several satellites, as seen from Jupiter, may be easily ascertained. By dividing the actual distances of the satellites from Jupiter by 206,265, we obtain the linear value of 1″ at such distance; and by dividing the actual diameters of the satellites respectively by this value, we obtain, in seconds, their apparent diameters as seen from Jupiter.

In making this calculation, however, it is necessary to take into account the magnitude of the semi-diameter of the planet, which is assumed to be 42,423 miles; since it is from the surface, and not from the centre, that the satellite is viewed.

It follows, from a calculation made on these principles, using the values inserted in (406) and (408), that the apparent magnitudes of the four satellites, seen from any part of the surface not far removed from the equator of the planet, are, for the first 35′ 50″, for the second 18′ 40″, for the third 18′ 12″, and for the fourth 8′ 58″.

The first satellite, therefore, has an apparent diameter equal to that of the moon; the second and third are nearly equal, and about half that diameter; and the apparent diameter of the other satellite is about the fourth part of that of the moon.

It may be easily imagined what various and interesting nocturnal phenomena are witnessed by the inhabitants of Jupiter, when the various magnitudes of these four moons are combined with the quick succession of their phases, and the rapid apparent motions of the first and second.

By the relation between the mean motions of the first three satellites, they never can be at the same time on the same side of Jupiter; so that whenever any one of them is absent from the firmament of the planet at night, one at least of the others must be present. The Jovian nights are, therefore, always moonlit, except during eclipses (which take place at every revolution), and often enlightened at once by three moons of different apparent magnitudes, and seen under different phases.

410. **Apparent magnitudes of Jupiter as seen from the satellites.**—Since the apparent diameter of the planet seen from a satellite is twice its horizontal parallax, that of each satellite as viewed from the surface of Jupiter, being respectively about $9^{\circ}\cdot5$, 6°, $3^{\circ}\cdot6$, and $2^{\circ}\cdot1$, it follows that the apparent diameter of Jupiter seen from the first satellite is about 19°, from the second 12°, from the third $7^{\circ}\cdot2$, and from the fourth $4^{\circ}\cdot2$. The disk of Jupiter, therefore, appears to the first with a diameter eighteen times greater, and a surface 320 times greater than that of the full moon.

411. **Mass of Jupiter.**—The following are the estimates of the mass of the planet obtained by processes susceptible of great precision, that of the sun being unity:

Laplace - - -	$\frac{1}{1067}$	Santini - - -	$\frac{1}{1050}$
Nicolai - - -	$\frac{1}{1054}$	Bessel - - -	$\frac{1}{1047\cdot87}$
Airy - - -	$\frac{1}{1046\cdot77}$	Krüger - - -	$\frac{1}{1047\cdot16}$

The computations by MM. Airy, Santini, and Bessel were conducted on principles such as to secure the greatest attainable precision, and their results have been confirmed by M. Krüger from the perturbations produced by Jupiter on Themis.

Since the mass of the sun is about 315,000 times that of the earth, while it is only 1050 times that of Jupiter, it follows that the mass of Jupiter exceeds that of the earth in the ratio of 3150 to 10·50, or 300 to 1.

The comparatively great mass of Jupiter explains the very short periods of his satellites compared with that of the moon.

At greater distances from Jupiter than that of the moon from the earth, they nevertheless revolve in periods much shorter than that of the moon, and are affected by centrifugal forces, which exceed that of the moon in a ratio which may be determined by the periods and distances, and which must be resisted by the attraction of a central mass proportionally greater than that of the earth. It would be easy to show that, if the earth were attended by a similar system of moons, at like distances from its centre, their periods would be about eighteen times greater than those of Jupiter's satellites.

412. **Their mutual perturbations.**— The mutual attractions of the masses of the satellites, and the inequality of the attraction of the sun upon them, produce an extremely complicated system of disturbing actions on their motions, which has nevertheless been brought with great success under the dominion of analysis by Laplace and Lagrange. This is especially the case with the three inner satellites, whose motions, but for this cause, would be sensibly uniform. The effect of these disturbing forces is nevertheless mitigated and limited by the very small excentricities and inclinations of the orbits of the satellites.

413. **Density of Jupiter.**— The volume of Jupiter being greater than that of the earth in the ratio of 1233 to 1, while its mass is greater in the inferior ratio of 300 to 1 nearly, it follows, that the density of the matter composing the planet, is less than the mean density of the earth in the ratio of the above numbers, or 0·27494. Its mean density is, therefore, about one-fourth of that of the earth.

414. **Masses and densities of the satellites.**—The masses of the satellites are determined by their mutual disturbances, and the densities are deduced as usual from a comparison of these masses with their volumes. In the following table are given the masses as compared with the primary and with the earth, and their densities as compared with the earth and with water.

Satellite.	Mass, that of Jupiter = 1.	Mass, that of Earth = 1.	Density, that of Earth = 1.	Density, that of Water = 1.
I.	0·0000173	0·00520	0·02016	0·1143
II.	0·0000232	0·00698	0·03015	0·1710
III	0·0000885	0·02663	0·06984	0·3960
IV.	0·0000427	0·01285	0·03925	0·2225

Thus it appears that the density of the matter composing these satellites is much smaller than those of any other bodies of the system whose densities are known.

It follows, therefore, that the first satellite must be composed of matter which is twice as light as cork, the density of which is

0·240; and that of the third, which consists of the heaviest matter, is not more dense than the lightest sort of wood, such, for example, as the common poplar, whose density is 0·383 (H. 91.)

It is remarkable that this extremely small degree of density is not found in the earth's satellite, the density of which, though less than that of the earth, is still more than twice the density of water.

The relation of the density of the earth to that of water in the preceding table, is inferred from the determination, by Mr. Baily, of the mean density of the earth by the method known as the Cavendish experiment (80). The values in the last column giving the density of the satellites would be increased if the result obtained from the Harton pendulum experiments had been used (81).

The planets Mercury and Mars, which are so nearly of the same magnitudes as the third and fourth satellites, show in a striking manner, the difference of the matter composing them, by the great difference of their densities. The mean specific weight of the materials composing these planets is nearly the same as that of those which compose the earth, while the materials of the third satellite are thirteen times, and that of the fourth twenty-five times lighter.

II. SATURN.

415. **Saturnian system.**— Beyond the orbit of Jupiter a space but little less in width than that which separates that planet from the sun is unoccupied. At its limit we encounter the most extraordinary object in the system,—a stupendous globe, nearly nine hundred times greater in volume than the earth, surrounded by two, at least, and probably by several thin flat rings of solid matter, outside which revolve a group of eight moons; this entire system moving with a common motion so exactly maintained, that no one part falls upon, overtakes, or is overtaken by another, in their course around the sun.

Such is the SATURNIAN SYSTEM, the central body of which was known as a planet to the ancients, the annular appendages and satellites being the discovery of modern times.

416. **Period.**— By the usual methods the sidereal period of Saturn has been ascertained to be 10759·22 days, or 29·457 years. The synodic period is about 378 days.

417. **Mean and extreme distances from the sun.**—The mean distance from the sun is 9·54; or more exactly 9·538852, that of the earth being = 1.

Taking the earth's mean distance as 91½ millions of miles, that

of Saturn will then be 872 millions of miles. The excentricity of Saturn's orbit being 0·056, this distance is liable to variation, being augmented in aphelion, and diminished in perihelion by the eighteenth part of its whole amount. The greatest distance of the planet from the sun is therefore about 921, and the least is about 823, millions of miles.

418. **Relative scale of orbit and distance from the earth.**—The relative proportion of the orbits of Saturn and the earth are represented in *fig.* 69, where E E′ E″ is the earth's orbit, and S S′ Saturn's distance from the sun. The four positions of the earth indicated are,


Fig. 69.

E when the planet is in opposition.
E‴ when the planet is in conjunction.
E′ in quadrature west of the sun.
E″ in quadrature east of the sun.

419. **Great scale of the orbital motion.**—The distance of Saturn from the sun is therefore so enormous, that if the whole earth's orbit, measuring nearly 200 millions of miles in diameter were filled with a sun, that sun seen from Saturn would be only about twenty-four times greater in its apparent diameter than is the actual sun seen from the earth. A cannon ball, moving at 500 miles an hour, would take about 200 years, and a railway train, moving 50 miles an hour, would take about 2000 years to move from Saturn to the sun. Light, which moves at the rate of nearly 200,000 miles per second, takes 1 hour 15 minutes to move over the same distance. Yet to this distance solar gravitation transmits its mandates, and is obeyed with the utmost promptitude and the most unerring precision.

Taking the diameter of Saturn's orbit at 1744 millions of miles, its circumference is 5479 millions of miles, over which it moves in 10,759 days. Its daily motion is therefore 509,280 miles, and its hourly 21,220 miles.

420. **No phases.**—It is evident from what has been explained in relation to Jupiter (384), that neither Saturn nor any more distant planet can have sensible phases.

421. **Stations and retrogression.**—From a comparison of the orbital motion and varying distance between the earth and Saturn, it appears that the stations of the planet take place at about 65 days before and after opposition. Since the earth gains upon the planet at the mean rate of $0^\circ\cdot9526$ per day, the angle at the sun corresponding to 65 days will be $61^\circ\cdot92$, which corresponds to an elongation of 113°. The planet is therefore stationary at elongation 67° east and west of opposition.

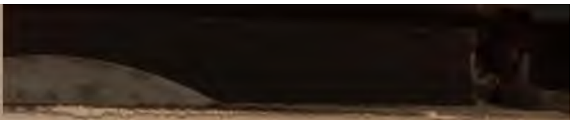
Its arc of retrogression varies from $6^\circ 41'$ to $6^\circ 55'$.

422. **Apparent and real diameter.**—This planet appears as a star of the first magnitude, with a faint reddish light. Its apparent brightness, compared with that of Mars, is greater than that which is due to their apparent magnitudes and distances, a circumstance which is explained, as in the case of Jupiter, by the more feebly reflective power of the surface of Mars.

The disk is visibly oval, and traversed, like that of Jupiter, by streaks of light and shade parallel to its greater axis; but these belts are much more faint and less pronounced than those of Jupiter. One principal grey belt, which lies along the greater axis of the disk, is almost unchangeable.

Sir William Herschel imagined that the disk had the form of an oblong rectangle, rounded at the corners, the length being in the direction of the belts. More recent observations and micrometrical measurements made at Königsberg, by Professor Bessel, and at Greenwich by Mr. Main, have shown, however, the true form to be an ellipse. According to the measures of M. Bessel, the apparent magnitude of the greater axis of the disk is $17''\cdot053$, and that of the lesser axis $15''\cdot394$. The observations of Professor Struve, made with the Dorpat instruments, give $17''\cdot991$ for the greater axis; the difference of the two estimates, $0''\cdot938$, being less than a second. The measures by Mr. Main, in 1848 and 1849, were made when the ring was invisible, by the double image micrometer (20), mounted on one of the principal equatorials at the Royal Observatory. The apparent angular magnitude at the planet's mean distance, resulting from these observations, is for the equatorial axis, $17''\cdot501$, and for the polar axis, $15''\cdot604$, giving for the value of the ellipticity, $\frac{1}{9\cdot227}$.

At the mean distance of Saturn, the linear value of one second



of space is 4228·2, the actual magnitudes, therefore, of the equatorial and polar diameters determined by the different observers are as follow:—

	Equatorial Diameter.	Polar Diameter.	Mean Diameter.
Bessel - - - -	72,103	65,089	68,596 miles
Struve - - - -	76,070	68,226	72,148 „
Main - - - -	73,998	65,977	69,988 „

The differences in the above results are no greater than might have been expected, considering the difficulty attending this class of astronomical observation; we may, therefore, definitely assume the actual diameter of the planet to be about the mean of the three determinations, or for the equatorial diameter, 74,057 miles, for the polar diameter, 66,215 miles, and for the mean diameter of the planet 70,136 miles.

The oblateness or ellipticity of Saturn may be expressed approximately as equal to one-tenth of the greater axis of the planet.

423. **Relative magnitudes of Saturn and the earth.**—The relative magnitudes of Saturn and the earth are represented in *fig.* 70, the volume of Saturn being 696 times greater than that of the earth.

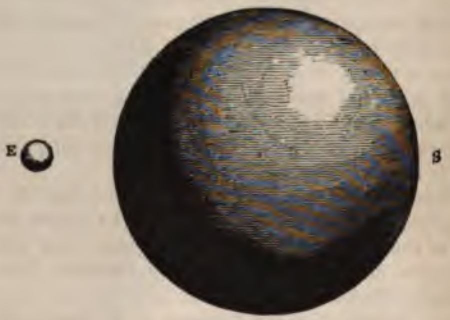


Fig. 70.

424. **Diurnal rotation.**—From observations on the apparent motion of spots on the disk of the planet, it has been ascertained to have a motion of rotation upon the shorter axis of the ellipse formed by its disk, in $10^h\ 29^m\ 17^s$. A terrestrial day is therefore equal to 2·2883 Saturnian days.

425. **Inclination of the axis to the orbit.**—The general direction of the motion of rotation has been ascertained to be such that the inclination of the equator of the planet to the plane of the orbit is 26° 48′ 40″, and its inclination to the plane of the ecliptic is 28° 10′ 44″·7.

The axis, like that of the earth, and those of the other planets,

whose rotation has been ascertained, is carried parallel to itself in the orbital motion of the planet.

The consequence of this arrangement is, that the year of Saturn is varied by the same succession of seasons, subject to the same range of temperature as those which prevail on our globe.

426. **Saturnian days and nights. Year.**—The alternation of light and darkness is therefore nearly the same as upon Jupiter. This rapid return of day, after an interval of five hours night, seems to assume the character of a *law* among the major planets, as the interval of twelve hours certainly does among the minor planets.

The year of Saturn is equal in duration to 10,759 terrestrial days. But since a terrestrial day is equal to 2·2883 Saturnian days, the number of Saturnian days in the Saturnian year must be about 24,620.

427. **Belts and atmosphere.**—Streaks of light and shade parallel in their general direction to the planet's equator have been observed on Saturn, similar, in all respects, to the belts of Jupiter, and affording like evidence of an atmosphere surrounding the planet attended with the like system of currents analogous to the trades. Such an inference involves, as in the former case, the admission of liquid producing vapour to form clouds and other meteorological phenomena.

428. **Solar light and heat.**—The apparent diameter of the sun as seen from Saturn is 9·539 times less than as seen from the

E

S

Fig. 71.

earth; and since its mean apparent diameter, as seen from the earth, is 1924″, its apparent diameter, as seen from Saturn, must be 3′ 21″·70.

The comparative apparent magnitudes are represented in *fig.* 71, where E represents the disk of the sun as seen from the earth, and S as seen from Saturn.

The intensity of solar light is less in the ratio of 1 to $9{\cdot}539^2 = 91$; and its optical and calorific influences with this reduced intensity are subject to the observations already made in the case of Jupiter (390).

429. **Rings.**—The invention of the telescope having invested astronomers with the power of approaching, for optical purposes, hundreds of times closer to the objects of their observation, one of the earliest results of the exercise of this improved sense was the discovery, that the disk of Saturn differed in a remarkable manner from those of the other planets in not being circular. It seemed at first to be a flattened oblong oval, approaching to the form of an elongated rectangle, rounded off at the corners. As the optical powers of the telescope were improved, it assumed the appearance of a great central disk, with two smaller disks, one at each side of it. These lateral disks took the appearance of handles or ears, like the handles of a vase or jar, and they were accordingly called the ansæ of the disk, a name which they still retain. At length, in 1659, Huygens explained the true cause of this phenomenon, and showed that the planet is surrounded by a ring of opaque solid matter, in the centre of which it is suspended, and that what appear as ansæ are those parts of the ring which lie beyond the disk of the planet at either side, which by projection are reduced to the form of the parts of an ellipse near the extremities of its greater axis, and that the open parts of the ansæ are produced by the dark sky visible through the space between the ring and the planet.

The improved telescopes and greatly multiplied number, and increased zeal and activity of observers, have supplied much more definite information as to the form, dimensions, structure, and position of this most extraordinary and unexampled appendage.

It has been ascertained, that it consists of an annular plate of matter, the thickness of which is very inconsiderable compared with the superficies. It is nearly, but not precisely concentric with the planet, and in the plane of its equator. This is proved by the coincidence of the plane of the ring with the general direction of the belts, and with that of the apparent motion of the spots by which the diurnal rotation of the planet has been ascertained.

When telescopes of adequate power are directed to the ring presented under a favourable aspect, dark streaks are seen upon its surface similar to the belts of the planet. One of these having been observed to have a permanence which seemed incompatible

with the admission of the same atmospheric cause as that which has been assigned to the belts, it was conjectured that it arose from a real separation or division of the ring into two concentric rings placed one within the other. This conjecture was converted into certainty by the discovery, that the same dark streak is seen in the same position on both sides of the ring. It has even been affirmed by some observers that stars have been seen in the space between the rings; but this requires confirmation. It is, however, considered as proved, that the system consists of two concentric rings of unequal breadth, one placed outside the other without any mutual contact.

The plane of the rings, being always at right angles to the axis of the planet, is, like the axis, carried by the orbital motion of the planet parallel to itself, so that during the year of Saturn, it undergoes changes of position in relation to the radius vector of the planet, or to a line drawn from the sun analogous to those which the earth's equator undergoes. Since the plane of the rings coincides with that of the Saturnian equator, therefore, it will be directed to the sun at the epochs of the Saturnian equinoxes; and, in general, the angle which the radius vector from the sun makes with the plane of the ring, will be the sun's declination as seen from Saturn. This angle, therefore, at the Saturnian solstices will be equal to the obliquity of Saturn's equator to his orbit, that is, to 26° 48′ 40″, and at the Saturnian equinoxes will be 0°(425).

430. **Position of nodes of ring and inclination to ecliptic.**—The investigation of the position of the plane of the ring in space was undertaken and conducted with great ability and success by Prof. Bessel, by means of an elaborate comparison of all the recorded observations on the phases of the ring from 1701 to 1832. The result proved that the line of intersection of the plane of the ring, and, therefore, that of the equator of the planet with the plane of the ecliptic, is parallel to that diameter of the celestial sphere which connects the two opposite points whose longitudes are 166° 53′ 8″·9 and 346° 53′ 8″·9, the former being the longitude of the point at which the rings pass from the south to the north of the ecliptic, and which is, therefore, the ascending node of the rings. It also resulted from this investigation that the angle formed by the plane of the rings, and, therefore, of the Saturnian equator with the plane of the ecliptic, is 28° 10′ 44″·7.

These longitudes and obliquity were those which corresponded to the 1st of January, 1800. It was shown that the nodes of the ring have a direct motion in longitude of 46″·462 per annum, their retrograde motion on the ecliptic being about 4″.

It resulted from the observations of Professor Struve, made with

the great Dorpat refractor, that the obliquity of the plane of the ring to that of the ecliptic is 28° 5′ 54″, subject to a possible error of 6′ 24″.

The observations and measurements of these two eminent astronomers are, therefore, in as perfect accordance as the degree of perfection to which the instruments of observation have been brought admits.

431. **Apparent and real dimensions of the rings.**—The breadth of the rings as well as of the intervals which separate them from each other and from the planet, have been submitted to very precise micrometric observations; and the results obtained by different observers do not differ from each other by a fortieth part of the whole quantity measured. In the following table are given the results of the micrometric observations of Professor Struve, reduced to the mean distance.

Section of Planet Measured.	Reference Letter.	Apparent Magnitude at mean Distance.	In Semi-diameters of the Planet.	Miles.
Semi-diameter of the planet	*r*	8″·995	1·000	38,035
Exterior semi-diameter of exterior-ring	*a*	20·047	2·229	84,763
Interior do. do.	*a′*	17·644	1·961	74,602
Breadth of exterior ring	*a—a′*	2·403	0·268	10,160
Exterior semi-diameter of interior ring	*b*	17·237	1·916	72,881
Interior do. do.	*b′*	13·334	1·482	56,379
Breadth of interior ring	*b—b′*	3·903	0·434	16,503
Width of interval between the rings	*a′—b*	0·407	0·045	1,721
Width of interval between planet and interior ring	*b′—r*	4·339	0·482	18,346
Breadth of the double ring, including interval	*a—b′*	6·713	0·747	28,384

The relative dimensions of the two rings, and of the planet within them, are represented in *fig.* 72, projected upon the common plane of the rings and the planet's equator. Each division of the subjoined scale represents 5,000 miles.

The visual angle subtended at the earth by the extreme diameter of the external ring, when the planet is in opposition, is 48″, which is about one thirty-seventh part of the moon's apparent diameter.

432. **Thickness of the rings.**—The thickness of the rings is so extremely minute, that the nicest micrometric observations have hitherto failed to supply the data necessary to determine it with any degree of precision or certainty. It is so inconsiderable, that when the plane of the ring is directed to the earth, and, consequently, the edge alone is presented to the eye, it is invisible even with telescopes of great power, or, if seen, it is so imperfectly defined as to elude all micrometric observation. When it was in this position in 1833, Sir J. Herschel observed it with a telescope,

which would certainly have rendered distinctly visible a line of light one twentieth of a second in breadth. Since the linear value of 1″ at Saturn's mean distance is about 4228 miles, it would

Fig. 72.

follow that the thickness is less than 210. Sir J. Herschel admits, however, that it may possibly be so great as 250 miles.

The thickness, is, therefore, certainly less than the 100th part of the extreme breadth of the two rings, and according to the scale on which the *fig.* 72 is drawn, it would be represented by the thickness of a leaf of the volume now before the reader.

433. **Conditions under which the ring becomes invisible from the earth.**—The rings of Saturn viewed from the earth may become invisible, either because the parts presented to the eye are not illuminated by the sun, or, being illuminated, have dimensions too small to subtend a sensible visual angle.

In every position assumed by the planet in its orbital motion, one side or the other of the rings is illuminated with more or less intensity, except at the Saturnian equinoxes, when, the plane of the

ring passing through the sun, its edge alone is illuminated. Owing to the extreme thinness of the plate of matter composing the rings, they cease in this case to be visible, except by feeble and uncertain indications observed with high magnifying powers. It has been inferred by Sir John Herschel, from observations made with telescopes of great power, that the major limit of their possible thickness is 250 miles. The visual angle which this thickness would subtend at the distance of Saturn in opposition, is 0″·064. The visual angle would, therefore, be less than the fifteenth part of a second.

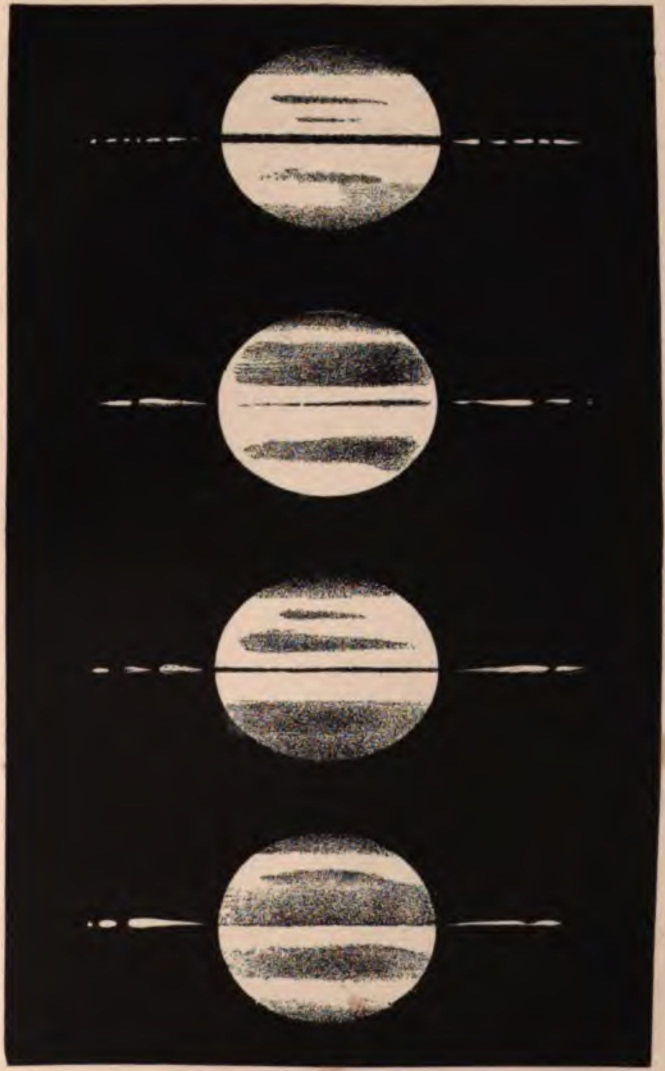
The rings, therefore, disappear from this cause at Saturn's equinoxes, which occur at intervals of $14\frac{3}{4}$ years.

When the dark side of the rings is exposed to the earth, it is evident that the sun and earth must be on opposite sides of the plane of the rings, and therefore that plane must have such a position that its direction would pass between the sun and the earth. This can only happen within a certain limited distance of the planet's equinoxes.

The disappearance of the rings of Saturn was well witnessed at the Saturnian equinox in 1848. The northern surface of the ring had then been visible for nearly fifteen years. The motions of the planet and the earth brought the plane of the ring to that position on the 22nd of April in which, its edge being presented to the earth, it became invisible, the sun being still north of the plane. On the 3rd of September the sun, passing through the plane of the ring, illuminated its southern surface, and, the earth being on the same side, the ring was visible. On the 12th, the earth again passing through the plane of the ring, its northern surface was exposed to the observer, which was invisible, the sun being on the southern side. The ring continued thus to be invisible until the 18th of January, 1849, when, the earth once more passing through the plane of the ring, the southern surface illuminated by the sun came into view. This side of the ring continued to be exposed to both the earth and the sun until 1861–2, the epoch of the last equinox, when a like succession of appearances and disappearances took place,—the sun and earth eventually passing to the northern side, on which they will continue for a like interval.

434. **Schmidt's observations and drawings of Saturn with the ring seen edgeways.**—At the Saturnian equinox which took place in 1848, a series of observations was made at Bonn, the results of which have demonstrated the existence of great inequalities of surface on the rings, having the character of mountains of considerable elevation. The observations were made and published, accompanied by seventeen drawings of the appearance

XX.



1

2

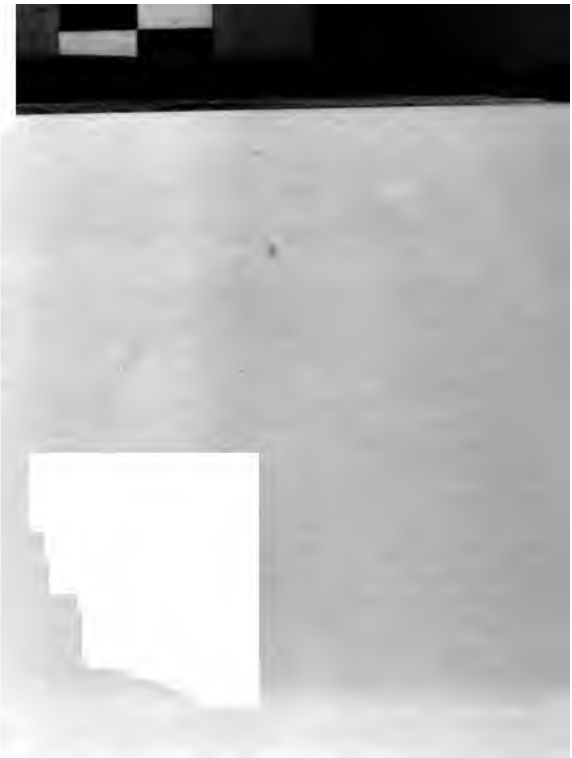
3

4

SATURN.

As seen at his equinox in 1848, by M. Schmidt.

1. June 26. 2. Sept. 4. 3. Sept 5. 4. Sept. 11.



of the planet, its belts, and ring, by M. Julius Schmidt, of the Bonn Observatory. *

We have selected from these drawings four, which are given in Plate XX.

On the 26th of June, the planet presented an appearance, *fig.* 1, closely resembling that of Jupiter, except that a dark streak was seen along its equator, produced by the shadow of the ring, the earth being then a little above the common plane of the ring and the sun. A few feeble streaks, of a greyish colour, were visible on each hemisphere, which however disappeared towards the poles. A very feeble star was seen at the western extremity of the ring, which was supposed to be one of the nearer satellites. The ring exhibited the appearance of a broken line of light projecting from each side of the planet's disk.

After this day the shadow across the planet disappeared, but was again faintly seen on the 25th of July.

The ring continued to be invisible until the 3rd of September, when a very slight indication of it was seen, but on the next night it became distinctly visible with an interruption in two places, as represented in *fig.* 2. The bright equatorial belt was divided into two unequal parts by the ring, the northern portion being the narrower. Three small satellites were seen on the prolongation of the direction of the ring.

On the 5th, the ring was symmetrically broken on both sides, *fig.* 3.

On the 7th, the western side was divided into three parts.

On the 11th, the ring and planet presented the appearance represented in *fig.* 4.

The broken and changing appearances of the ring on this occasion can only be explained by the admission of great inequalities of surface rendering some parts of the ring so thick as to be visible, and others so thin as to be invisible, when presented edgeways to the observer.

435. **Observations of Herschel.** — These observations of Schmidt are corroborative of those made at a much earlier epoch by Sir W. Herschel, who discovered the existence of appearances on the surface of the rings indicating mountainous inequalities.

436. **Supposed multiplicity of rings.** — Some observations made at Rome and elsewhere gave grounds for the conjecture, that the outer ring instead of being double, is quintuple, and that instead of having a single division, there are four. It was even affirmed with some confidence, that the ring was septuple, and consisted of seven concentric rings suspended in the same plane.

* *Astronomische Nachrichten*, Vol. xxviii. No. 650.

These conjectures were founded upon the supposed permanence of the black circular and concentric streaks which are observed upon the surface of the rings, and which are quite analogous to the belts of the planet. This assumed permanence has not, however, been re-observed, although the planet has been examined by numerous observers, with telescopes of very superior power to those with which the observations were made which formed the ground of the conjecture.

The passage of Saturn diametrically across any fixed star of sufficient magnitude, at the epoch of the Saturnian solstice, when the plane of the ring is inclined at the greatest angle to the visual line, would supply the most eligible means of testing the multiple structure of the rings; for in that case the light of the star would be seen with the telescope to flash through each successive opening between ring and ring, provided that the width of such opening were sufficient to allow the visual ray to clear the thickness of the rings.

437. **Ring probably triple — observations of Messrs. Lassell and Dawes.** — Nevertheless, there are well ascertained appearances on the surface of the outer ring, which have been thought to indicate a second division, and that the ring is triple. So early as 1838, Professor Encke noticed an appearance which indicated a division, and even made drawings in which such a division is indicated. (See *Transactions of the Berlin Academy of Sciences*, 1838.) On the 7th of September, 1843, Messrs. Lassell and Dawes, unaware apparently of Encke's observations, saw, with a nine-feet Newtonian reflector constructed by Mr. Lassell, what they considered to be a division of the outer ring. The observation was made under a magnifying power of 450, which gave a sharply defined disk to the planet, and exhibited the principal division of the rings as a continuous, distinctly seen, black streak, extending all round the surface of the ring. A dark line on the outer ring, near the extremities of the ellipse, was not only distinctly seen, but an estimate of its breadth, compared with that of the principal division, was made by both these observers, from which it appeared that this breadth was about one third of the space which separates the two principal rings. Its place upon the outer ring was a little less than half the entire width of the ring from the outer edge, and it was equally visible at both ends of the ellipse. No appearances could be discovered of any other divisions, although the shading of the belts on the inner ring was distinguished.

438. **Researches of Bessel corroborate these conjectures.** — Bessel compared all the observations made on the rings from 1700 to 1833, with the view of determining with more precision the nodes of the ring, and found that the ring has frequently been

seen when it ought to have been invisible, if the several concentric rings of which it consists were all in the same plane and had a uniform surface. He found that the appearances and disappearances had no certain or regular epochs, and did not correspond with each other even to the same observer, using the same instrument. Thus Schwabe, at Dessau, saw the line of light formed by the rings near their equinox resolve itself into a series of points. Schmidt, as has been stated, saw it become a broken line, changing its form from night to night. Other observers saw the ring disappear on one side of the disk, while it was apparent on the other. From all these phenomena, it is inferred that probably the rings are in planes slightly different; that their edge is not regularly circular, but notched and dinged; and that their surfaces are characterised by considerable mountainous undulations.

439. **Discovery of an inner ring imperfectly reflective and partially transparent.**—But the most surprising result of recent telescopic observations of this planet has been the discovery of a ring, composed, as it would appear, of matter reflecting light much more imperfectly than the planet or the rings already described; and what is still more extraordinary, transparent to such a degree, that the body of the planet can be seen through it.

In 1838, Dr. Galle, at that time assistant at the Berlin observatory, noticed a phenomenon, which he described as a gradual shading off of the inner ring towards the surface of the planet, as if the solid matter of the ring were continued beyond the limit of its illuminated surface, this continuation of the surface being rendered visible by a very feeble illumination such as would attend a penumbra upon it; and measures of this obscure surface were published by him in the *Transactions of the Berlin Academy of Sciences* of that year.

The subject, however, attracted very little attention until towards the close of 1850, when Professor Bond of Cambridge, Massachusetts, U.S. and Mr. Dawes in England, not only recognised the phenomenon noticed by Dr. Galle, but ascertained its character and features with great precision. The observations of Professor Bond which were made on the 15th of November, were not known in England until the 4th of December; but the phenomenon was very fully and satisfactorily seen and described by Mr. Dawes, on the 29th of November. That astronomer, on the 3rd of December, called the attention of Mr. Lassell to it, who also witnessed it on that evening at the observatory of Mr. Dawes; and both immediately published their observations and descriptions of it, which appeared in Europe simultaneously with those of Professor Bond.

It was not, however, until 1852 that the transparency was fully ascertained. From some observations made in September, Mr.

Dawes strongly suspected its existence, and about the same time it was clearly seen at Madras by Captain Jacob, and in October by Mr. Lassell at Malta, whither he had removed his 20-feet reflector to obtain the advantages of a lower latitude and more serene sky. The result of these observations has been the conclusive proof of the unique phenomenon of a semi-transparent annular appendage to this planet.

440. **Drawing of the planet and rings as seen by Mr. Dawes.**—The planet surrounded by this compound system of rings is represented in Plate XXI. The drawing is reduced from the original sketch, made by Mr. Dawes, of the planet as seen with his refractor of $6\frac{1}{3}$ inch aperture, at Wateringbury, in November 1852. Another representation of the planet as seen by Mr. Lassell at Malta, in December 1852, has been lithographed, and is almost identical with that of Mr. Dawes. In both drawings the form and appearance of the obscure ring and its partial transparency are rendered quite manifest. The principal division of the bright rings is visible throughout its entire circumference. The black line, supposed to be a division of the outer ring, is visible in the drawing of Mr. Dawes; but was not at all seen by Mr. Lassell.

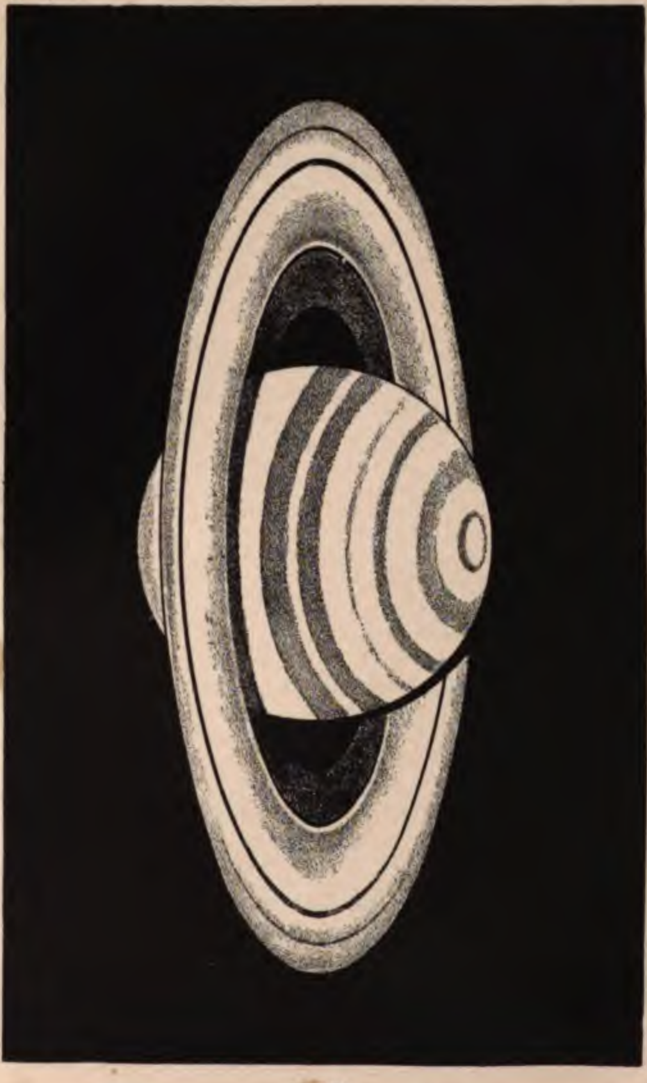
A remarkably bright thin line, at the inner edge of the inner bright ring, which appears in the Plate XXI., was distinctly seen by Mr. Dawes in 1851 and 1852.

The inner bright ring is always a little brighter than the planet. It is not, however, uniformly bright. Its illumination is most intense at the outer edge, and grows gradually fainter towards the inner edge, where it is so feeble as to render it somewhat difficult to ascertain its exact limit. It would seem as if the imperfectly reflective quality at the inner edge approaches to that of the obscure ring recently discovered. The open space between the ring and the planet has the same colour as the surrounding sky.

441. **Bessel's calculation of the mass of the rings.**—Bessel has attempted to determine the mass of the system of rings by the perturbation they produce upon the orbit of the sixth satellite. He estimates it at 1-118th part of the mass of the planet. The thickness of the rings being too minute for measurement, no estimate of the density of the matter composing them can be hence obtained; but if the density be assumed to be equal to that of the planet (which will be explained hereafter), it would follow that the thickness of the rings would be about 138 miles, which is not far from the estimate of their thickness made by observers. If this thickness be admitted, the edge of the rings would subtend an angle of the 1-32nd part of a second at Saturn's mean distance. Hence it will be understood that the ring must disappear, even in powerful telescopes, when presented edgeways.

XXI.

North.



South.

SATURN.

As seen in November 1852, with a refractor of 6⅓ inch aperture, at Wateringbury, near Maidstone.

By W. R. Dawes.

442. **Stability of the rings.**—One of the circumstances attending this planet, which has excited most general astonishment, is the fact that the globe of the planet, and two, not to say more, stupendous rings, carried round the sun with a velocity of 22,000 miles an hour, subject to a periodical variation not inconsiderable, due to the varying distance of the planet from the sun, should nevertheless maintain their relative position for countless ages undisturbed, the globe of the planet remaining still poised in the middle of the rings, and the rings, two or several, as the case may be, remaining one within the other without material connection or apparent contact, no one of the parts of this most marvellous combination having ever gained or lost ground upon the other, and no apparent approach to collision having taken place, notwithstanding innumerable disturbing actions of bodies external to them.

443. **Cause assigned for this stability.**—The happy thought of bringing the rings under the common law of gravitation, which gives stability to satellites, has supplied a striking and beautiful solution for this question. The manner in which the attraction of gravitation, combined with centrifugal force, causes the moon to keep revolving round the earth without falling down upon it by its gravity on the one hand, or receding indefinitely from it by the centrifugal force on the other, is well understood. In virtue of the equality of these forces, the moon keeps continually at the same mean distance from the earth while it accompanies the earth round the sun. Now it would be easy to suppose another moon revolving by the same law of attraction at the same distance from the earth. It would revolve in the same time, and with the same velocity, as the first. We may extend the supposition with equal facility to three, four, or a hundred moons, at the same distance. Nay, we may suppose as many moons placed at the same distance round the earth as would complete the circle, so as to form a ring of moons touching each other. They would still move in the same manner and with the same velocity as the single moon.

If such a ring of moons were beaten out into the thin broad flat rings which actually surround Saturn, the circumstances would be somewhat changed, inasmuch as the periods of each concentric zone would vary in a certain ratio, depending on its distance from the centre of Saturn, so that each such zone would have to revolve more rapidly than those within it, and less rapidly than those outside it. But if the entire mass were coherent, as the component parts of a solid body are, the complete ring might revolve in a periodic time less than that due to its exterior, and longer than that due to its interior parts. In fact,

the period of its revolution would be the period due to a certain zone lying near the middle of its breadth, exactly as the time of oscillation of a compound pendulum is that which is proper to the centre of oscillation (M. 506). Indeed, the case of the oscillation of a pendulum, and the conditions which determine the centre of oscillation, afford a very striking illustration of the physical phenomena here contemplated.

444. **Rotation of the rings.** — Now the observations of Sir William Herschel on certain appearances upon the surface of the rings, led to the discovery that they actually have a revolution round their common centre and in their own plane, and that the time of such revolution is very nearly equal to the periodic time of a satellite whose distance from the centre of the planet would be equal to that of the middle point of the breadth of the rings.

But if the principles above explained be admitted, it would follow that each of the concentric zones into which the ring is divided would have a different time of revolution, just as satellites at different distances have different periodic times; and it is extremely probable that such may be the case, because no observations hitherto made afford results sufficiently exact and conclusive as to either establish or overturn such an hypothesis.

It appears, therefore, that the stability of the rings is explicable upon the same principle as the stability of a satellite.

445. **Excentricity of the rings.** — The fact that the system of rings is not concentrical with the planet resulted from some observations made by Messrs. Harding and Schwabe; after which the subject was taken up by Professor Struve, who, by delicate micrometric observations and measurements executed with the great Dorpat instrument, fully established the fact, that the centre of the rings moves in a small orbit round the centre of the planet, being carried round by the rotation of the rings.

446. **Arguments for the stability founded on the excentricity.** — Sir John Herschel has indicated, in this deviation of the centre of the rings from the centre of the planet, another source of the stability of the Saturnian system. If the rings were "mathematically perfect in their circular form, and exactly concentric with the planet, it is demonstrable that they would form (in spite of their centrifugal force) a system in a state of *unstable equilibrium*, which the slightest external power would subvert — not by causing a rupture in the substance of the rings, but by precipitating them, *unbroken*, on the surface of the planet. For the attraction of such a ring or rings on a point or sphere excentrically situate within them is not the same in all directions, but tends to draw the point or sphere toward the nearest part of the

ring, or away from the centre. Hence, supposing the body to become, from any cause, ever so little excentric to the ring, the tendency of their mutual gravity is, not to correct but to increase this excentricity, and to bring the nearest parts of them together. Now, external powers, capable of producing such excentricity, exist in the attractions of the satellites: and in order that the system may be *stable*, and possess within itself a power of resisting the first inroads of such a tendency, while yet nascent and feeble, and opposing them by an opposite or maintaining power, it has been shown that it is sufficient to admit the rings to be *loaded* in some part of their circumference, either by some minute inequality of thickness, or by some portions being denser than others. Such a load would give to the whole ring to which it was attached somewhat of the character of a heavy and sluggish satellite, maintaining itself in an orbit with a certain energy sufficient to overcome minute causes of disturbance, and establish an average bearing on its centre. But even without supposing the existence of any such load — of which, after all, we have no proof — and granting, therefore, in its full extent, the general instability of the equilibrium, we think we perceive, in the periodicity of all the causes of disturbance, a sufficient guarantee of its preservation. However homely be the illustration, we can conceive nothing more apt in every way to give a general conception of this maintenance of equilibrium, under a constant tendency to subversion, than the mode in which a practised hand will sustain a long pole in a perpendicular position resting on the finger, by a continual and almost imperceptible variation of the point of support. Be that, however, as it may, the observed oscillation of the centres of the rings about that of the planet is in itself the evidence of a perpetual contest between conservative and destructive powers — both extremely feeble, but so antagonising one another as to prevent the latter from ever acquiring an uncontrollable ascendency, and rushing to a catastrophe."

Sir. J. Herschel further observes, that since "the least difference of velocity between the planet and the rings must infallibly precipitate the one upon the other, never more to separate (for, once in contact, they would attain a position of stable equilibrium, and be held together ever after by an immense force), it follows either that their motions in their common orbit round the sun must have been adjusted to each other by an external power with the minutest precision, or that the rings must have been formed about the planet while subject to their common orbital motion, and under the full and free influence of all the acting forces."

The rings must obviously form a most remarkable object in the

firmament to observers stationed on Saturn, and must play an important part in their uranography. The problem to determine their apparent magnitude, form, and position, in relation to the fixed stars, the sun, and Saturnian moons, has, therefore, been regarded as a question of interesting speculation, if not of great scientific importance. The subject has, accordingly, more or less engaged the attention of astronomers. The conclusion, however, at which they have arrived, and the views which have been generally expressed and adopted respecting it, are open to considerable doubt, if not altogether erroneous. It is not the object of this work to enter controversially on any disputed part of astronomical science, we must therefore leave the subject in the hands of those who are interested in a subject, which to say the least, may be considered speculative.*

447. **Satellites.**— Saturn is attended by eight satellites, seven of which move in orbits whose planes coincide very nearly with that of the equator of the planet, and therefore with the plane of the rings. The orbit of the remaining satellite, which is the most distant, is inclined to the equator of the planet at an angle of about 12° 14′, and to the plane of the planet's orbit at nearly the same angle.

448. **Their nomenclature.**— In the designations of the satellites, much confusion has arisen from the disagreement of astronomers as to the principle upon which the numerical order of the satellites should be determined. Some name them first, second, third, &c., in the order of their discovery; while others designate them in the order of their distances from Saturn. It has been proposed to remove all confusion, by giving them names, taken, like those of the planets, from the heathen divinities. The following metrical arrangement of these names, in the order of their distances, proceeding from the most distant inwards, has been proposed, as affording an artificial aid to the memory:—

Iapetus, Titan; Rhea, Dione, Tethys †;
Enceladus, Mimas ——.

449. **Order of their discovery.**— Since this was suggested, the eighth satellite situate between Iapetus and Titan has been discovered, and called Hyperion.

* These prevailing errors respecting the uranography of Saturn, form the materials of a long and interesting paper by Dr. Lardner, published in the *Memoirs of the Royal Astronomical Society*, Vol. XXII. Those who feel interested in the consideration of this subject may consult this memoir with advantage. —E. D.

† Pronounced Tĕthys.

[redacted]

The order of their discovery was as follows:—

Name.	Discoverers.	When discovered.
Titan.	Huygens.	March, 1655.
Iapetus.	D. Cassini.	October, 1671.
Rhea.	Do.	December, 1672.
Dione.	Do.	March, 1684.
Tethys.	Do.	March, 1684.
Enceladus.	Sir W. Herschel.	August, 1789.
Mimas.	Do.	September, 1789.
Hyperion.	Messrs. Lassell and Bond.	September, 1848.

Hyperion was discovered on the same night, the 19th of September, 1848, by Mr. Lassell of Liverpool, and Professor W. C. Bond of the University of Cambridge in the United States.

450. **Their distances and periods.**—The periodic times and mean distances of these bodies from the centre of Saturn, ascertained by the same kind of observations as already explained in the case of the satellites of Jupiter, are as follows:—

Order.	Name.	Period.					Distance.
		D.	H.	M.	S.	Saturnian days.	Semidiameters of Saturn.
1	Mimas - -	0	22	37	22·9	2·16	3·3607
2	Enceladus -	1	8	53	6·7	3·14	4·3125
3	Tethys - -	1	21	18	25·7	4·32	5·3390
4	Dione - -	2	17	41	8·9	6·26	6·8398
5	Rhea - -	4	12	25	10·8	10·34	9·5528
6	Titan - -	15	22	41	25·2	36·49	22·1450
7	Hyperion - -	21	7	7	40·8	48·73	28· ?
8	Iapetus - -	79	7	53	40·4	181·53	64·3590

451. **Elongations and relative distances.**—The greatest elongations of the satellites from the primary, and the scale of their distances in relation to the diameters of the planet and its rings, are represented in *fig.* 73, assuming, for convenience, that the angular value of the semidiameter of the planet is equal to 10″.

It appears, therefore, that the orbit of the most remote of the satellites subtends a visual angle of only 1286″ at the earth, being about two-thirds of the apparent diameter of the sun or moon, and within this small visual space all the vast physical machinery and phenomena which we have here noticed are in operation, and within such a space have these extraordinary discoveries been made. The apparent diameter of the external edge of the rings is only 44″, or the fortieth part of the apparent diameter of the sun or moon; yet within that small circle have been observed and measured the planet, its belts, atmosphere, and rotation, and the two rings, their magnitude, rotation, and the lineaments of their surface.

452. **Various phases and appearances of the satellites to observers on the planet.**— All that has been said of the phases and appearances of the moons of Jupiter, as presented to the inhabitants of that planet, is equally applicable to the satellites of Saturn, with this difference, that instead of four there are eight moons continually revolving round the planet, and exhibiting all the monthly changes to which we are accustomed in the case of the solitary satellite of the earth.

Fig. 73.

The periods of Saturn's moons, like those of Jupiter, are short, with the exception of those most remote from the primary. The nearest passes through all its phases in 22½ hours, and the fourth, counting outwards, in less than 66 hours. The next three have months varying from 4 to 21 terrestrial days.

These seven moons move in orbits whose planes are nearly coincident with the plane of the rings. The consequence of this arrangement is, that they are always visible by the inhabitants of both hemispheres when they are not eclipsed by the shadow of the planet.

The two inner satellites are seen making their rapid course along the external edge of the ring, within a very small apparent distance of it. The motion of the nearest is so rapid as to be perceivable, like that of the hour-hand of a colossal time-piece. It describes 360° in 22½ hours, being at the rate of 16° per hour, or 16′ per minute, so that in two minutes it moves over a space equal to the apparent diameter of the moon.

The eighth, or most remote satellite, is in many respects exceptional, and different from all the others. Unlike these, it moves in an orbit inclined at a considerable angle to the plane of the rings.

It is exceptional also in its distance from the primary, being removed to the distance of 64 semidiameters of Saturn. The only case analogous to this presented in the solar system is that of the earth's moon, the distance of which is 60 semidiameters of the primary.

453. **Magnitudes of the satellites.**— Owing to the great distance of Saturn, the dimensions of the satellites have not been ascertained. The sixth in order, proceeding outwards, is, however, known to be the largest, and it appears certain that its volume is

little less than that of the planet Mars. The three satellites immediately within this, Rhea, Dione, and Tethys, are smaller bodies, and can only be seen with telescopes of great power. The other two, Mimas and Enceladus, require instruments of the very highest power and perfection, and atmospheric conditions of the most favourable nature, to be observable at all. Sir J. Herschel says, that at the time they were discovered by his father "they were seen to thread, like beads, the almost infinitely thin fibre of light to which the ring, then seen edgeways, was reduced, and for a short time to advance off it at either end, speedily to return, and hastening to their habitual concealment behind the body."

454. **Apparent magnitudes as seen from Saturn.**—The real magnitudes of the satellites, the sixth excepted, being unascertained, nothing can be inferred with any certainty respecting their apparent magnitudes as seen from the surface of Saturn, except what may be reasonably conjectured upon analogies to other like bodies of the system. The satellites of Jupiter being all greater than the moon, while one of them exceeds Mercury in magnitude, and another is but little inferior in volume to that planet, it may be assumed with great probability of truth that the satellites of Saturn are at least severally greater in their actual dimensions than our moon.

If this be admitted, their probable apparent magnitudes as seen from Saturn may be inferred from their distances. The distance of the first, Mimas, from the nearest part of the surface of the planet, is only 90,000 miles, or nearly 2½ times less than the distance of the moon; the distance of the second is about half that of the moon; that of the third about two-thirds, and that of the fourth about five-sixths, of the moon's distance. If these bodies, therefore, exceed the moon in their actual dimensions, their apparent magnitudes as seen from Saturn will exceed the apparent magnitude of the moon in a still greater ratio than that in which the distance of the moon from the earth exceeds their several distances from the surface of Saturn. Of the remaining satellites, little is as yet known of the seventh, and apparently the most minute, Hyperion, which was only discovered in 1848; and the great magnitude of the sixth, Titan, renders it probable that, notwithstanding its great distance from Saturn, it may still appear with a disk not very much less than that of the moon.

455. **Rotation on their axes.**—The case of the moon, and the observations made on the satellites of Jupiter, raise the presumption that it is a general law of secondary planets to revolve on their axes in the times in which they revolve round their primary. The great distance of Saturn has deprived observers hitherto of the power of testing this law by the Saturnian system. Certain

appearances, however, which have been observed in the case of the great satellite Titan indicate, at least with regard to it, such a rotation. The variation of its apparent brightness in different parts of its orbit is very conspicuous, and the changes have a fixed relation to its elongation, the same degree of brightness always corresponding to the same position of the satellite in relation to its primary. Now this is an effect which would be explicable on the supposition that different sides of the satellite reflect light with different degrees of intensity, and that it revolves on its axis in the same time that it revolves round its primary. It has been observed that, when the satellite has eastern elongation, it has ceased to be visible, from which it has been inferred that the hemisphere then turned to the earth has so feeble a reflective power that the light proceeding from it is insufficient to affect the eye in a sensible degree. The improvement of telescopes has enabled observers to follow it at present through the entire extent of its orbit, but the diminution of its lustre on the eastern side of the planet is still so great, that it is only seen with the greatest difficulty.

456. **Mass of Saturn.**— The mass of Saturn is ascertained by the motion of his satellites, and is found to be the 3500th part of the mass of the sun, or about 90 times greater than that of the earth.

457. **Density.**— Since the mass of Saturn is only 100 times greater than that of the earth, while his volume is about 1000 times greater, it follows that this planet is composed of matter whose mean density is about ten times less than that of the earth; and since the density of the earth is about five and a half times greater than that of water, it follows that the density of Saturn is a little more than half that of water. This is the density of the light sorts of wood, such as cedar and poplar, and is about twice the density of cork (H. 91).

III. Uranus.

458. **Discovery of Uranus.**— While occupied in one of his surveys of the heavens on the night of the 13th of March, 1781, the attention of Sir William Herschel was attracted by an object which he did not find registered in the catalogue of stars, and which presented in the telescope an appearance obviously different from that of a fixed star. On viewing it with increased magnifying powers, it presented a sensible disk; and after the lapse of some days, its place among the fixed stars was changed. This object must, therefore, have been either a comet or a planet; and Sir W. Herschel in the first instance announced it as the former. When, however, submitted to further and more continued observation, it was found to move in an orbit nearly circular, inclined at a small

angle to the plane of the ecliptic, and to have a disk sensibly circular.

It appeared, therefore, to have the characters, not of a comet, but a planet revolving outside the orbit of Saturn. It was named the "Georgium Sidus" by Sir W. Herschel, in compliment to his friend and patron George III. This name not being accepted by foreign astronomers, that of "Herschel" was proposed by Laplace, and to some extent for a time adopted. Definitely, however, the scientific world has agreed upon the name "Uranus," by which this member of the system is now universally designated.

459. **Period, by synodic motion.**—Owing to the great length of the period of this planet, those methods of determination which require the observation of one or more complete revolutions could not be applied to it. The synodic period, however, or the interval between two successive oppositions, being only 369·4 days, supplied a means of obtaining a first approximation. This gives a period of 30,643 days.

460. **By the apparent motion in quadrature.**—When a planet is in quadrature, its visual direction being a tangent to the earth's orbit, its apparent place is not affected by the earth's orbital motion. In the quadrature which precedes opposition, the earth moves directly *towards* the planet; and in the quadrature which follows opposition, it moves directly *from* the planet. In neither case, therefore, would its motion produce any apparent change of place in the planet. It follows, therefore, that when a planet is in quadrature, its apparent motion is due exclusively to its own motion and not at all to that of the earth. The daily motion of the planet as then observed is, therefore, the actual daily increment of its geocentric longitude.

But in the case of a planet, such as Uranus, or even Saturn, whose distance from the sun bears a large ratio to the earth's distance, the geocentric motion of the planet will not differ sensibly from the heliocentric motion; and, therefore, the geocentric daily increment of the planet's longitude observed when in quadrature may, to obtain an approximative value of the period, be taken as the daily increment of the heliocentric longitude. If this increment be expressed by l, we shall have

$$P=\frac{360^\circ}{l}.$$

Now, it is found that the apparent daily increment of the planet's longitude when in quadrature is $42''\cdot23$. If 360° be reduced to seconds, we shall then have

$$P=\frac{1296000}{42\cdot23}=30689.$$

By more accurate calculation, the periodic time has been determined at 30,686·82 days, or 84 years.

461. **Heliocentric motion.**—The mean daily heliocentric motion of the planet is, therefore, more exactly, 42″·233.

462. **Distance from the sun.**—The mean distance of Uranus from the sun is 19·183 times that of the earth, and, consequently, the actual distance is about 1,753,869,000 miles, its distance from the earth being, when in opposition, therefore 1662 millions of miles.

The excentricity of the orbit of Uranus being 0·0466, these distances are liable to only a very small variation. The distance from the sun is increased in aphelion, and diminished in perihelion by less than a twentieth of its entire amount. The plane of the orbit coincides very nearly with that of the ecliptic.


Fig. 74.

463. **Relative orbit and distance from the earth.**—The relative proportion of the orbits of Uranus and the earth are represented in *fig.* 74, where E E′ E″ is the orbit of the earth, and S U the distance of Uranus from the sun. The four positions of the earth, corresponding to the opposition, conjunction, and quadratures of the planet, are represented as in the former cases.

464. **Vast scale of the orbital motion.**—The distance of Uranus from the sun being above nineteen times that of the earth, and the earth being at such a distance that light, moving at the rate of nearly 200,000 miles per second, takes about eight minutes to come from the sun to the earth; it follows that it will take $19 \times 8 = 152$ minutes, or about two hours and a half, to move from the sun to Uranus. Sunrise and sunset are, therefore, not perceived by the inhabitants of that planet for two hours and a half after they really take place, for the sun does not appear to rise or set until the light moving from it, at the moment it touches the plane of the horizon, reaches the eye of the observer.

The diameter of the orbit of Uranus measuring, in round numbers, 3,500 millions of miles, its circumference measures 11,000 millions of miles, over which the planet moves in 30,687 days. Its mean daily motion is therefore 358,000 miles, and its hourly motion, consequently, about 15,000 miles.

465. **Apparent and real diameters.**—The apparent diameter of Uranus in opposition exceeds 4″ by a small fraction. At the distance of the planet from the earth, in that position, the linear value of 1″ is 8060 miles; the actual diameter of the planet by this method is therefore 33,329 miles, being about half that of Saturn, and a little more than $4\frac{1}{3}$ times that of the earth. The diameter generally adopted is 33,247 miles.

466.—**Surface and volume.**—The surface of Uranus is therefore 18 times, and its volume about 74 times that of the earth.

467. **Diurnal rotation and physical character of surface unascertained.**—The vast distance of this planet, and its consequent small apparent magnitude and faint illumination, have rendered it hitherto impracticable to discover any indications of its diurnal rotation, the existence of an atmosphere, or any of the other physical characters which the telescope has disclosed in the case of the nearer of the great planets.

468. **Solar light and heat.**—The apparent diameter of the sun as seen from Uranus, is less than as seen from the earth in the ratio of 1 to 19. The magnitude of the sun's disk at the earth being supposed to be represented by E, *fig.* 75, its magnitude seen from Uranus would be U.

Fig. 75.

The illuminating and warming powers of the solar rays, *under the same physical conditions*, are therefore $19^2 = 361$ times less at Uranus than at the earth.

469. **Suspected rings.**—It was at one time suspected by Sir W. Herschel that this planet was surrounded by two systems of rings with planes at right angles to each other. Subsequent observation has not realised this conjecture.

470. **Satellites.**—It has been ascertained that Uranus, like the other major planets, is attended by a system of satellites, the number of which is not yet certainly determined, and which, from the great remoteness of the Uranian system, cannot be seen at all except by the aid of the most perfect and powerful telescopes.

Sir W. Herschel, soon after discovering this planet, announced the existence of a system of six satellites attending it. On the 11th of January, 1787, the second and fourth in order of distance from the planet were discovered, the remaining four having been noticed in the interval between the beginning of 1790, and the end of 1798. The periods and distances of the satellites as determined generally by Sir W. Herschel, are expressed in the following Table:—

Order.	Period.				Distances in semidiameters of Uranus.
	D.	H.	M.	S.	
1	5	21	?		13·1 ?
2	8	16	56	52	17·0
3	10	23	?		19·8 ?
4	13	11	8	59·0	22·8
5	38	2	?		45·5 ?
6	107	12	?		91·0 ?

Subsequent observations have confirmed this discovery so far only as relates to the second and fourth satellites, the first, third, fifth, and sixth, having only been seen by Sir W. Herschel. The others not having been re-observed, notwithstanding the vast improvement which has taken place in the construction of telescopes, and the greatly multiplied number and increased activity and zeal of observers, must be considered, to say the least, as problematical.

Considerable attention has been devoted to this planet by Mr. Lassell and others, with the object of removing the uncertainty which is attached to the number of satellites belonging to it. The two principal satellites of Sir W. Herschel, the second and fourth, are by far the most conspicuous, and their distances and periods have been ascertained with all desirable accuracy and certainty. Two inner satellites named Ariel and Umbriel revolving around the primary within the second of Sir W. Herschel's, have been, since 1847, frequently observed, particularly by Mr. Lassell, at Malta, in 1852, to which place he transferred his 20-feet reflector; by which means, and in consequence of the superior brilliancy of the sky and clearness of atmosphere to that to which he was accustomed at Liverpool, Mr. Lassell was enabled to make a considerable series of measures of positions and distances of the two principal satellites, Titania and Oberon, as well as of the two recently discovered inner satellites, Ariel and Umbriel. These names have been suggested by Mr. Lassell as an appropriate nomenclature for the four satellites whose identities have been established.

In addition to the periods and distances given above, which are those determined by Sir W. Herschel, we insert also, in the following table the periods and distances of the four satellites, of the existence of which there is no doubt.

Name of Satellite.	Period.				Distance in semidiameters of Uranus.
	D.	H.	M.	S.	
Ariel	2	12	29	20·7	7·44
Umbriel	4	3	28	8·0	10·37
Titania	8	16	56	24·9	17·01
Oberon	13	11	6	55·2	22·75

The number of satellites attending upon Uranus must, therefore, be assumed to amount to four, until by further improvements in the construction of telescopes, giving an increased penetrating power, observers may be enabled to detect others, or to confirm the existence of some of those which have hitherto been supposed to form a portion of the Uranian system.

471. **Anomalous inclination of their orbits.**—Contrary to the law which prevails without any other exception in the motions of the bodies of the solar system, the orbits of the satellites of Uranus are inclined to the plane of the orbit of the planet, and therefore to that of the ecliptic, at an angle of 78° 58′, being little less than a right angle, and their motions in these orbits are retrograde, that is to say, their longitudes as seen from Uranus continually *decrease.*

When the earth has such a position that the visual direction is at right angles to the line of nodes, the angle under the plane of the orbit and the visual line will be 78° 58′; and in certain positions of the planet they will be seen, as it were, *in plan.* Being nearly circular, the satellites will in such a position be visible revolving round the primary throughout their entire orbits, the projections not sensibly differing from circles.

472. **Apparent motion and phases as seen from Uranus.**—The diurnal rotation and the direction of the axis of the planet being unascertained, the inclination of the orbits to the planet's equator is consequently unknown. It appears, however, that all the orbits have the same line of nodes, and are in a common plane or nearly so. Twice in each revolution of the planet this plane passes through the sun, when the satellites exhibit the same succession of phases to the planet as the moon presents to the earth, except so far as they are modified by the effects of the diurnal parallax, which are considerable, especially in the case of the nearer satellites.

Twice in each revolution of the planet, at epochs exactly intermediate between the former, the line of nodes being at right angles to the line joining the sun and planet, the plane of the satellites' orbits is nearly perpendicular to the same line. In this case the satellites during their entire revolution suffer no other change of phase than what may be produced by the diurnal parallax, and appear continually with the same phases as that which the moon presents at the quarters.

In the intermediate position of the planet a complicated variety of phases will be presented, which may be traced and analysed by giving due attention to the change of direction of the line of nodes of the satellites' orbits to the line joining the planet with the sun.

473. **Mass and density of Uranus.**—Some uncertainty still attends the determination of the elements of these more distant and recently discovered planets. The mass and density of Uranus are only provisionally determined. The mass is assumed to be the 24,900th part of that of the sun, and the density the sixth of that of the earth. Some observers make the mass considerably greater.

IV. Neptune.

474. **Discovery of Neptune.**—The discovery of this planet constitutes one of the most signal triumphs of mathematical science, and marks an era which must be for ever memorable in the history of physical investigation.

If the planets were subject only to the attraction of the sun, they would revolve in exact ellipses, of which the sun would be the common focus; but being also subject to the attraction of each other, which, though incomparably more feeble than that of the presiding central mass, produces sensible and measurable effects, consequent deviations from these elliptic paths, called PERTURBATIONS, take place. The masses and relative motions of the planets being known, these disturbances can be ascertained with such accuracy that the position of any known planet at any epoch, past or future, can be determined with the most surprising degree of precision.

If, therefore, it should be found that the motion which a planet is observed to have, is not in accordance with that which it ought to have, subject to the central attraction of the sun, and the disturbing actions of the surrounding planets, it must be inferred that some other disturbing attraction acts upon it, proceeding from an undiscovered cause, and, in this case, a problem novel in its form and data, and beset with difficulties which might well appear insuperable, is presented to the physical astronomer. If the solution of the problem, to determine the disturbances produced upon the orbit of a planet by another planet, whose mass and motions are known, be regarded as a stupendous achievement in physical and mathematical science, how much more formidable must not the converse question be regarded, in which the disturbances are given to find the planet!

Such was, nevertheless, the problem of which the discovery of Neptune has been the astonishing solution.

Although no exposition of the actual process by which this great intellectual achievement has been effected could be comprehended without the possession of an amount of mathematical knowledge far exceeding that which is expected from the readers of treatises much less elementary than the present volume, we may not be altogether unsuccessful in attempting to illustrate the principle

on which an investigation, attended with so surprising a result, has been based, and even the method upon which it has been conducted, so as to strip the proceeding of much of that incomprehensible character which, in the view of the great mass of those who consider it without being able to follow the steps of the actual investigation, is generally attached to it, and to show at least the spirit of the reasoning by which the solution of the problem has been accomplished.

For this purpose, it will be necessary, *first*, to explain the nature and character of those disturbances which were observed, and which could not be ascribed to the attraction of any of the known planets; and, *secondly*, to show in what manner an undiscovered planet revolving outside the known limits of the solar system could produce such effects.

475. **Unexplained disturbances observed in the motions of Uranus.**—The planet Uranus, revolving at the extreme limits of the solar system, was the object in which were observed those disturbances which, not being the effects of the action of any of the known planets, raised the question of the possible existence of another planet exterior to it, which might produce them.

After the discovery of the planet by Sir W. Herschel, in 1781, its motions, being regularly observed, supplied the data by which its elliptic orbit was calculated, and the disturbances produced upon it by the masses of Jupiter and Saturn ascertained, the other planets of the system, by reason of their remoteness, and the comparative minuteness of their masses, not producing any sensible effects. Tables founded on these results were computed, and ephemerides constructed, in which the places at which the planet ought to be found from day to day for the future, were duly registered.

The same kind of calculations which enable the astronomer thus to predict the future places of the planet, would, as is evident, equally enable him to ascertain the places which had been occupied by the planet in times past. By thus examining, retrospectively, the apparent course of the planet over the firmament, and comparing its computed places at particular epochs with those of stars which had been observed, and which had subsequently disappeared, it was ascertained that several of these stars had in fact been Uranus itself, whose planetary character had not been recognised from its appearance, owing to the imperfection of the telescopes then in use, nor from its apparent motion, owing to the observations not having been sufficiently continuous and multiplied.

In this way it was ascertained that Uranus had been observed, and its position recorded as a fixed star, six times by Flamsteed; viz., once in 1690, once in 1712, and four times in 1715;—once

by Bradley in 1753, once by Mayer in 1756, and twelve times by Lemonnier between 1750 and 1771.

Now, although the observed positions of these objects, combined with their subsequent disappearance, left no doubt whatever of their identity with the planet, their observed places deviated sensibly from the places which the planet ought to have had according to the computations founded upon its motions after its discovery in 1781. If these deviations could have been shown to be irregular and governed by no law, they would be ascribed to errors of observation. If, on the other hand, they were found to follow a regular course of increase and decrease in determinate directions, they would be ascribed to the agency of some undiscovered disturbing cause, whose action at the epochs of the ancient observations was different from its action at more recent periods.

The ancient observations were, however, too limited in number and too discontinuous to demonstrate in a satisfactory manner the irregularity or the regularity of the deviation. Nevertheless, the circumstance raised much doubt and misgiving in the mind of Bouvard, by whom the tables of Uranus were constructed; and considering that these tables, in which every correction for perturbation indicated by the best existing theories was applied, were based upon the modern observations, it was anticipated that the agreement between the observed and tabular places of the planet would continue for a considerable period of time. When, on examination, it was found impossible to reconcile the ancient observations of Flamsteed, Lemonnier, &c. with the orbit required to satisfy the observations made after the discovery of the planet in 1781, the difficulties attending the explanation of these irregularities were so great, that M. Bouvard stated that he would leave to futurity the decision of the question whether these deviations were due to errors of observation, or to an undiscovered disturbing agent. We shall presently be enabled to appreciate the sagacity of this reserve.

The motions of the planet continued to be assiduously observed, and were found to be in accordance with the tables for about fourteen years from the date of the discovery of the planet. About the year 1795, a slight discordance between the tabular and observed places began to be manifested, the latter being a little in advance of the former, so that the observed longitude L of the planet was greater than the tabular longitude L'. After this, from year to year, the advance of the observed upon the tabular place increased, so that the excess $L-L'$ of the observed above the tabular longitude was continually augmented. The increase of $L-L'$ continued until 1822, when it became stationary, and afterwards began to decrease.

This decrease continued until about 1830-31, when the deviation L—L′ disappeared, and the tabular and observed longitudes again agreed. This accordance, however, did not long prevail. The planet soon began to fall behind its tabular place, so that its observed longitude L, which before 1831 was greater than the tabular longitude L′, was now less; and the distance L′—L of the observed behind the tabular place increased from year to year, and still increases, amounting in November, 1858, to 3′ 38″ of longitude.

It appears, therefore, that in the deviations of the planet from its computed place, there was nothing irregular and nothing compatible with the supposition of any cause depending on the accidental errors of observation. The deviation, on the contrary, increased gradually in a certain direction to a certain point; and having attained a maximum, then began to decrease, which decrease still continues.

The phenomena must, therefore, be ascribed to the regular agency of some undiscovered disturbing cause.

476. **A planet exterior to Uranus would produce a like effect.**—It is not difficult to demonstrate that deviations from its computed place, such as those described above, would be produced by a planet revolving in an orbit having the same or nearly the same plane as that of Uranus, which would be in heliocentric conjunction with that planet at the epoch at which its advance beyond its computed place attained its maximum.

Let A B C D E F, *fig.* 76, represent the arc of the orbit of Uranus described by the planet during the manifestation of the perturbations. Let N N′ represent the orbit of the supposed undiscovered planet in the same plane with the orbit of Uranus. Let *a*, *b*, *c*, *d*, *e*, and *f* be the positions of the latter when Uranus is at the points A, B, C, D, E, and F. It is, therefore, supposed that Uranus when at D is in heliocentric conjunction with the supposed planet, the latter being then at *d*.

The directions of the orbital motions of the two planets are indicated by the arrows beside their paths; and the directions of the disturbing forces* exercised by the supposed planet on Uranus are indicated by the arrows beside the lines joining that planet with Uranus.

Now, it will be quite evident that the attraction exerted by the supposed planet at *a* on Uranus at A tends to accelerate the latter. In like manner, the forces exerted by the supposed planet at *b* and *c* upon Uranus at B and C tend to accelerate it. But as Uranus

* To simplify the explanation, the effect of the attraction of Uranus on the sun is omitted in this illustration.

approaches to D the direction of the disturbing force, being less and less inclined to that of the orbital motion, has a less and less accelerating influence, and on being in the direction D *d* at right angles to the orbital motion, all accelerating influence ceases.

Fig. 76.

After passing D the disturbing force is inclined *against* the motion, and instead of accelerating retards it; and as Uranus takes successively the positions E, F, &c. it is more and more inclined, and its retarding influence more and more increased, as will be evident if the directions of the retarding force and the orbital motion, as indicated by the arrows, be observed.

It is then apparent that from A to D the disturbing force accelerating the orbital motion, will transfer Uranus to a position in advance of that which it would otherwise have occupied; and after passing D, the disturbing force retarding the planet's motion will continually reduce this advance, until it bring back the planet to the place it would have occupied had no disturbing force acted; after which, the retardation being still continued, the planet will fall behind the place it would have had if no disturbing force had acted upon it.

Now it is evident that these are precisely the *kind* of disturbing forces which act upon Uranus; and it may, therefore, be inferred that the deviations of that planet from its computed place are the physical indications of the presence of a planet exterior to it, moving in an orbit whose plane either coincides with that of its own orbit, or is inclined to it at a very small angle, and whose mass and distance are such as to give to its attraction the degree of intensity necessary to produce the alternate acceleration and retardation which have been observed.

Since, however, the intensity of the disturbing force depends conjointly on the quantity of the disturbing mass and its distance, it is easy to perceive that the same disturbance may arise from different masses, provided that their distances are so varied as to compensate for their different weights or quantities of matter. A double mass at a fourfold distance will exert precisely the same attraction. The question, therefore, under this point of view, belongs to the class of intermediate problems, and admits of an

infinite number of solutions. In other words, an unlimited variety of different planets may be assigned exterior to the system, which would cause disturbances observed in the motion of Uranus, so nearly similar to those observed as to be distinguishable from them only by observations more extended and elaborate, than any to which that planet could possibly have been submitted since its discovery.

477. **Researches of Messrs. Le Verrier and Adams.**—The idea of taking these departures of the observed from the computed place of Uranus as the data for the solution of the problem to ascertain the position and motion of the planet which could cause such deviations, occurred, nearly at the same time, to two astronomers, neither of whom at that time had attained either the age or the scientific standing which would have raised the expectations of achieving the most astonishing discovery of modern times.

M. Le Verrier, in Paris, and Mr. J. C. Adams, of Cambridge, engaged in the investigation, each without the knowledge of what the other was doing, and believing that he stood alone in his adventurous and, as would then have appeared, hopeless attempt. Nevertheless, both not only solved the problem, but did so with a completeness that filled the world with astonishment and admiration, in which none more ardently shared than those who, from their own attainments, were best qualified to appreciate the difficulties of the question.

The question, as has been observed, belonged to the class of intermediate problems. An infinite number of different planets might be assigned which would be equally capable of producing the observed disturbances. The solution, therefore, might be theoretically correct, but practically unsuccessful. To strip the question as far as possible of this character, certain conditions were assumed, the existence of which might be regarded as in the highest degree probable. Thus, it was assumed that the disturbing planet's orbit was in or nearly in the plane of that of Uranus, and therefore in that of the ecliptic; that its motion in this orbit was in the same direction as that of all the other planets of the system, that is, according to the order of the signs; that the orbit was an ellipse of very small excentricity; and finally that its mean distance from the sun was, in accordance with the general progression of distances noticed by Bode, nearly double the mean distance of Uranus. This last condition, combined with the harmonic law, gave the inquirer the advantage of the knowledge of the period, and therefore of the mean heliocentric motion.

Assuming all these conditions as provisional data, the problem was reduced to the determination, at least as a first approximation, of the mass of the planet and its place in its orbit at a given

epoch, such as would be capable of producing the observed alternate acceleration and retardation of Uranus.

The determination of the heliocentric place of the planet at a given epoch would have been materially facilitated if the exact time at which the amount of the advance (L — L′) of the observed upon the tabular place of the planet had attained its maximum were known; but this, unfortunately, did not admit of being ascertained with the necessary precision. When a varying quantity attains its maximum state, and, after increasing, begins to diminish, it is stationary for a short interval; and it is always a matter of difficulty, and often of much uncertainty, to determine the exact moment at which the increase ceases and the decrease commences. Although, therefore, the heliocentric place of the disturbing planet could be nearly assigned about 1822, it could not be determined with the desired precision.

Assuming, however, as nearly as was practicable, the longitude of Uranus at the moment of heliocentric conjunction with the disturbing planet, this, combined with the mean motion of the sought planet, inferred from its period, would give a rough approximation to its place for any given time.

478. **Elements of the sought planet assigned by these geometers.** — Rough approximations were not, however, what MM. Le Verrier and Adams sought. They aimed at more exact results; and, after investigations involving all the resources, and exhausting all the vast powers of analysis, these eminent geometers arrived independently at the following elements of the undiscovered planet: —

Elements of supposed Planet.	Le Verrier.	Adams.
Epoch of the elements - - -	1 Jan. 1847.	6 Oct. 1846.
Mean longitude at the epoch - -	318° 47′·4	323° 2′
Mean distance of planet from sun -	36·1539	37·2474
Excentricity of the orbit - -	0·107610	0·120615
Longitude of perihelion - - -	284° 45′·8	299° 11′
Mass (sun = 1) - - - -	0·00010727	0·0015003

479. **Its actual discovery by Dr. Galle of Berlin.** — On the 23rd of September, 1846, Dr. Galle, one of the astronomers of the Royal Observatory at Berlin, received a letter from M. Le Verrier, announcing to him the principal results of his calculations, informing him that the longitude of the sought planet must then be 326°, and requesting him to look for it. Dr. Galle, assisted by Professor Encke, accordingly did "look for it," and found it that very night. It appeared as a star of the 8th magnitude, having the longitude of 326° 52′, and consequently only 52′ from the place assigned by M. Le Verrier. The calculations of Mr. Adams,

reduced to the same date, gave for its apparent place 329° 19′, being 2° 27′ from the place where it was actually found.

480. **Its predicted and observed places in near proximity.** — To illustrate the relative proximity of these remarkable predictions to the actual observed place, let the arc of the ecliptic, from long. 323° to long. 330°, be represented in *fig.* 77. The place assigned by M. Le Verrier for the sought planet is indicated by the small circle at L, that assigned by Mr. Adams by the small circle at A, and the place at which it was actually found by the dot at N. The distances of L and A from N may be appreciated by the circle which is described around the dot N, and which represents the apparent disk of the moon.

Fig. 77.

The distance of the observed place of the planet from the place predicted by M. Le Verrier was less than two diameters, and from that predicted by Mr. Adams less than five diameters, of the lunar disk.

481. **Corrected elements of the planet's orbit.** — In obtaining the elements given above, Mr. Adams based his calculations on the observations of Uranus made up to 1840, while the calculations of M. Le Verrier were founded on observations continued to 1845. On subsequently taking into computation the five years ending 1845, Mr. Adams concluded that the mean distance of the sought planet would be more exactly taken at 33·33.

After the planet had been actually discovered, and observations of sufficient continuance were made upon it, the following was found to be its more exact elements, having been computed by M. Kowalski, of Kazan. These elements appear to represent the orbit of Neptune sufficiently well up to the present time: —

Elements of Neptune.	At Berlin Mean Time.
Epoch of the elements - - - -	1 Jan. 1850, M. Noon.
Mean longitude at epoch - - -	334° 36′ 30″.
Mean distance from sun - - -	30·0339.
Eccentricity of orbit - - -	0·0091740.
Longitude of perihelion - - -	50° 16′ 39″.
——— ascending node - -	130° 7′ 45″.
Inclination of orbit - - - -	1° 47′ 1″.
Periodic time - - - - -	164·5910 years.
Mean annual motion - - - -	2° 1870.

482. **Discrepancies between the actual and predic elements explained.** — Now it will not fail to strike every who devotes the least attention to this interesting question, t considerable discrepancies exist, not only between the eleme presented in the two proposed solutions of this problem, between the actual elements of the discovered planet and both these solutions. There were not wanting some who, viewing th discordances, did not hesitate to declare that the discovery of planet was the result of chance, and not, as was claimed, of mat matical reasoning, since, in fact, the planet discovered was identical with either of the two planets predicted.

To draw such a conclusion from such premises, however, betr a total misapprehension of the nature and conditions of the probl If the problem had been determinate, and, consequently, one wh admits of but one solution, then it must have been inferred, eit that some error had been committed in the calculations wh caused the discordance between the observed and computed ments, or that the discovered planet was not that which was sou and which was the physical cause of the observed disturbance Uranus. But the problem, as has been already explained, be more or less indeterminate, admits of more than one, — nay, of indefinite number of different solutions, so that many differ planets might be assigned which would equally produce the distu ances which had been observed; and this being so, the discorda between the two sets of predicted elements, and between both them and the actual elements, are nothing more than might h been anticipated, and which, except by a chance against which probabilities were millions to one, were, in fact, inevitable.

So far as depended on reasoning, the prediction was verified far as depended on chance, it failed. Two planets were assign both of which lay within the limits which fulfilled the conditi of the problem. Both, however, differed from the true plane particulars which did not affect the conditions of the probl All three were circumscribed within those limits, and subject such conditions as would make them produce those deviations disturbances which were observed in the motions of Uranus, which formed the immediate subject of the problem.

483. **Comparison of the effects of the real and predic planets.** — It may be satisfactory to render this still more cl by exhibiting in immediate juxtaposition the motions of hypothetical planets of MM. Le Verrier and Adams and the pla actually discovered, so as to make it apparent that any one of three under the supposed conditions, would produce the obser disturbances. We have accordingly attempted this in *fig.* where the orbits of Uranus, of Neptune, and of the planets assig

by MM. Le Verrier and Adams are laid down, with the positions of the planets respectively in them for every fifth year, from 1800

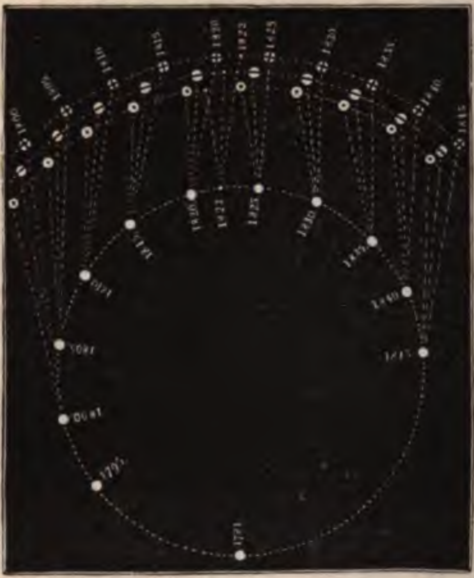


Fig. 78.

to 1845 inclusively. This plan is, of course, only roughly made; but it is sufficiently exact for the purposes of the present illustration. The places of Uranus are marked by $\bigcirc$, those of Neptune by $\odot$, those of M. Le Verrier's planet by $\ominus$, and those of Mr. Adams's planet by $\oplus$.

It will be observed that the distances of the two planets assigned by MM. Le Verrier and Adams, as laid down in the diagram, differ less from the distance of the planet Neptune than the mean distances given in their elements differ from the mean distance of Neptune. This is explained by the excentricities of the orbit, which, in the elements of both astronomers, are considerable, being nearly an eighth in one and a ninth in the other, and by the positions of the supposed planets in their respective orbits.

If the masses of the three planets were equal, it is clear that the attraction with which Le Verrier's planet would act upon Uranus, would be less than that of the true planet, and that of Adams's planet still more so, each being less in the same ratio as

the square of its distance from Uranus is greater than that of Neptune. But if the planets are so adjusted that what is lost by distance is gained by the greater masses, this will be equalised, and the supposed planet will exert the same disturbing force as the actual planet, so far as relates to the effects of variation of distance. It is true that, throughout the arcs of the orbits over which the observations extend, the distances of the three planets in simultaneous positions are not everywhere in exactly the same ratio, while their masses must necessarily be so; and, therefore, the relative masses, which would produce perfect compensation in one position, would not do so in others. This cause of discrepancy would operate, however, under the actual conditions of the problem, in a degree altogether inconsiderable, if not insensible.

But another cause of difference in the disturbing action of the real and supposed planets would arise from the fact that the directions of the disturbing forces of all the three planets are different, as will be apparent on inspecting the figure, in which the degree of divergence of these forces at each position of the planets is indicated; but it will be also apparent that this divergence is so very inconsiderable that its effect must be quite insensible in all positions in which Uranus can be seriously affected. Thus, from 1800 to 1815, the divergence is very small. It increases from 1815 to 1835; but it is precisely here, near the epoch of heliocentric conjunction, which took place in 1822, that all the three planets cease to have any direct effect in accelerating the motion of Uranus. When the latter planet passes this point sufficiently to be sensibly retarded by the disturbing action, as is the case after 1835, the divergence again becomes inconsiderable.

From these considerations it will therefore be understood, that the disturbances of the motion of Uranus, so far as these were ascertained by observation, would be produced without sensible difference, either by the actual planet which has been discovered, or by either of the planets assigned by MM. Le Verrier and Adams, or even by an indefinite number of others which might be assigned, either within the path of Neptune, or between it and that of Adams's planet, or, in fine, beyond this — within certain assignable limits.

484. **No part of the merit of this discovery ascribable to chance.** — That the planets assigned by MM. Le Verrier and Adams are not identical with the planet to the discovery of which their researches have conducted practical observers is, therefore, true; but it is also true that, if they or either of them had been identical with it, such excessive amount of agreement would have been purely accidental, and not at all the result of the sagacity of the mathematician. All that human sagacity could do with the

data presented by observation was done. Among an indefinite number of *possible* planets capable of producing the disturbing action, two were assigned, both of which were, for all the purposes of the inquiry, so nearly coincident with the real planet as inevitably and immediately to lead to its discovery.

485. **Period.** — After a complete revolution of the earth, Neptune is found to advance in its course no more than 2°·187, and consequently its period is 164·591 years.

486. **Distance from the sun.** — The mean distance of Neptune from the sun is 30·0370, assuming the distance of the earth from the sun to be 1.

487. **Relative orbits and distances of Neptune and the earth.**—It appears then that the system possesses another member still more remote from the common centre of light, heat, and attraction. In *fig.* 79 the earth's orbit is represented at EE‴; and a part of that of Neptune, on the same scale, is represented at N. The actual distance of N from S is rather more than thirty times that of E from S. The mean distance of Neptune from the sun is, therefore, about 2,746,000,000 miles.

488. **Apparent and real diameter.**—The apparent diameter of the planet, seen when in opposition, is about 2″·9. Its distance from the earth being, then, 2654 millions of miles, and the linear value of 1″ at this distance being 12,867 miles, the actual diameter of the planet will be 37,314 miles.

The diameter of the planet is, therefore, a little greater than that of Uranus, about half that of Saturn, and about four and a half times that of the earth.

According to Mr. Hind, the apparent diameter is only 2″·6, a value which, he says, is deduced from careful measurements made with some of the most powerful European telescopes. This value would make the diameter of Neptune about the same as that of Uranus.

489. **Satellite of Neptune.**—A satellite of this planet was discovered by Mr. Lassell in

Fig. 79.

October, 1846, and was afterwards observed by other astronomers both in Europe and the United States. The first observations then made raised some suspicions as to the presence of another satellite as well as of a ring analogous to that of Saturn. Notwithstanding the numerous observers, and the powerful instruments which have been directed to the planet since the date of these observations, nothing has been detected which has had any tendency to confirm these suspicions.

The existence of the satellite first seen by Mr. Lassell has, however, not only been fully established, but its motion, and the elements of its orbit, have been ascertained, first by the observations of M. Otto Struve in September and December, 1847, and later and more fully by those of his late relative M. Auguste Struve, in 1848-9.

From these observations it appears that the distance of the satellite from the planet at its greatest elongation subtends an angle of 18″ at the earth; and since the diameter of the planet subtends an angle of 2″·8 at the same distance, it follows, therefore, that the distance of the satellite from the centre of the planet is equal to thirteen semi-diameters of the latter.

The mean daily angular motion of the satellite round the centre of the planet is, according to the observations of Mr. Lassell, made at Malta, 61°·0866, and consequently the period of the satellite is 5·8769 days, or $5^{d}\ 21^{h}\ 2^{m}\cdot 7$, a result which is subject to an error not exceeding 5 minutes.

If the semi-diameter of Neptune be 18,700 miles, the actual distance of the satellite from the surface of the planet is 224,400 miles, being a little less than the distance of the moon from the earth's centre.

490. **Mass and density.**—This discovery of a satellite has supplied the means of determining the mass, and therefore the density, of the planet. Professor Pierce, calculating by the principles already explained, has found that the mass of Neptune is the 18,780th part of the mass of the sun; and since its diameter is about the 23⅓rd, and its volume the 13,000th, part of that of the sun, its density will be about two-thirds that of the sun, and about the sixth part of the density of the earth.

Other estimates make the mass different. According to Professor Bond it is the 19,400th, and according to Mr. Hind, from a discussion of Mr. Lassell's observations made at Malta, the 17,500th, while M. Struve makes it the 14,446th part of the mass of the sun.

491. **Apparent magnitude of the sun at Neptune.**—The apparent diameter of the sun, as seen from Neptune, being 30 times less than from the earth, is about 60″; the sun, therefore,

appears of the same magnitude as Venus seen as a morning or evening star.

The relative apparent magnitudes are exhibited in *fig.* 80, at E and N.

Fig. 80.

It would, however, be a great mistake to infer that the light of the sun at Neptune approaches in any degree to the faintness of that of Venus at the earth. If Venus, when that planet appears as a morning or evening star, with the apparent diameter of 60″, had a full disk (instead of one halved or nearly so, like the moon at the quarters), and if the actual intensity of light on its surface were equal to that on the surface of the sun, the light of the planet would be exactly that of the sun at Neptune. But the intensity of the light which falls on Venus is less than the intensity of the light on the sun's surface, in the ratio of the square of Venus' distance to that of the sun's semi-diameter, upon the supposition that the light is propagated according to the same law as if it issued from the sun's centre; that is, as the square of 37 millions to the square of half a million nearly, or as $37^2 : \frac{1}{4}$, that is, as 5476 to 1. If, therefore, the surface of Venus reflected (which it does not) all the light incident upon it, its apparent light at the earth (considering that little more than half its illuminated surface is seen) is about 11,000 times less than the light of the sun at Neptune.

Small, therefore, as is the apparent magnitude of the sun at Neptune, the intensity of its daylight is probably not less than that which would be produced by about 20,000 stars shining at once in the firmament, each being equal in splendour to Venus when that planet is brightest.

In addition to these considerations, it must not be forgotten that all such estimates of the comparative efficiency of the illuminating and heating power of the sun is based upon the supposition that

his light is received under like physical conditions; and that many conceivable modifications in the physical state of the body or medium, on or into which the light falls, and in the structure of the visual organs which it affects, may render light of an extremely feeble intensity as efficient as much stronger light is found to be under other conditions.

492. **Suspected ring of Neptune.** — Messrs. Lassell and Challis have at times imagined that indications of some such appendage as a ring, seen nearly edgewise, were perceptible upon the disk of Neptune. These conjectures have not yet received any confirmation. When the declination of the planet will have so far increased as to present the ring, if such an appendage be really attached to the planet, at a less oblique angle to the visual ray, the question will probably be decided.

CHAPTER XVII.

ECLIPSES, TRANSITS, AND OCCULTATIONS.

493. **Interposition of celestial objects.** —The objects which in such countless numbers are scattered over the firmament being at distances and in positions infinitely various, and many of them being in motion, so that the directions of lines drawn from one to another are constantly varying, it must occasionally happen that three will come into the same line, or nearly so. Such a contingency produces a class of occasional astronomical phenomena which are invested with a high popular as well as a profound scientific interest. The rareness with which some of them are presented, their sudden and, to the vulgar mass, unexpected appearance, and the singular phenomena which often attend them, strike the popular mind with awe and terror. To the astronomer, geographer, and navigator, they subserve important uses, among which the determination of terrestrial longitudes, the more exact estimation of the sun's distance from the earth (which is the standard and modulus of all distances in the celestial spaces), the discovery of the mobility of light, and the measure of its velocity, hold foremost places.

When one of the extremes of the series of the three bodies which thus assume a common direction is the sun, the intermediate body deprives the other extreme body, either wholly or partially, of the illumination which it habitually receives. When one of the extremes is the earth, the intermediate body intercepts,

wholly or partially, the other extreme body from the view of observers situate at places on the earth which are in the common line of direction, and the intermediate body is seen to pass across the other extreme body as it enters upon and leaves the common line of direction. The phenomena resulting from such contingencies of position and direction are variously denominated ECLIPSES, TRANSITS, and OCCULTATIONS, according to the relative apparent magnitudes of the interposing and obscured bodies, and according to the circumstances which attend them.

494. **General conditions which determine the phenomena of interposition when one of the extreme objects is the earth.**—If the interposing and intercepted objects have disks of sensible magnitude, the effects attending their interposition will depend on the magnitude of the diameters of their disks and the apparent distance between their centres.

Let D express the apparent distance between the centres of the two disks. Let r be the semi-diameter of the nearer, and r' that of the more distant disk.

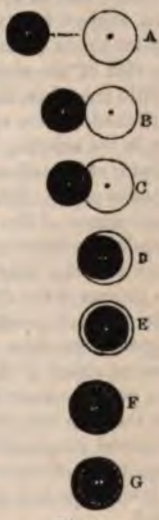


Fig. 81.

495. **Condition of no interposition.—External contact.**—If D be greater than $r+r'$, as represented at A, *fig.* 81, the disks must be entirely outside each other, and consequently no interposition can take place. The nearest points of the edges of the disks are, in this case, at a distance equal to the difference between D and $r+r'$, that is, $D-(r+r')$. If $D=r+r'$, as at B, the disks will touch without interposition. This is called the position of EXTERNAL CONTACT.

496. **Partial interposition.**—If D be less than $r+r'$, the nearer disk will be partially interposed, as at C. In this case, the greatest breadth of the obscured part of the more remote disk is $(r+r')-D$. It is evident that the less the distance D is, the greater will be this breadth, and the greater the part obscured.

497. **Internal contact of interposing disk.**—If the interposing disk be less than the more distant, it will reduce the latter to a crescent, the points of the horns of which meet, as represented at D, when $D=r-r'$, that is, when the distance between the centres is equal to the difference of the apparent semi-diameters.

498. **Centrical interposition of lesser disk.**—If in the same case the centres coincide, as at E, the nearer disk, covering all

the central portion of the more distant, will leave uncovered around it a regular ring or annulus of visible surface, the breadth of which will be the difference $r-r'$ of the semi-diameters.

499. **Complete interposition.**—If the nearer disk be greater than the more remote, and the distance D between the centres be not greater than $r-r'$, the difference of the semi-diameters, the more remote disk will be completely covered, and will continue so until the centres separate to a greater distance than $r-r'$, as represented at F and G.

I. Solar Eclipses.

500. **Solar eclipses.**—The case of the sun and moon presents all these various appearances. The disks, though nearly equal, are each subject to a variation of magnitude confined within certain narrow limits as has been already explained; and, in consequence, the disk of the moon is sometimes a little greater, and sometimes a little less, than that of the sun. Their centres move, as has been explained, in two apparent circles on the firmament; that of the sun in the ecliptic, and that of the moon in a circle inclined to the ecliptic at a small angle of about 5°. These circles intersect at two opposite points of the firmament called the moon's nodes (196). In consequence of the very small obliquity of the moon's orbit to the ecliptic, the distance between these paths, even at a considerable distance at either side of the node, is necessarily small. Now, since the centres of the disks of the sun and moon must each of them pass once in each revolution through each node, it will necessarily happen from time to time that they will be both at the same moment either at the node itself, or at some points of their respective paths so near it, that their apparent distance asunder will be less than the sum of their apparent semi-diameters, and either total or partial interposition must take place, according to the relative magnitudes of their disks, and to the distance between the points of their respective paths at which their centres are simultaneously found.

501. **Partial solar eclipse.**—If the apparent distance D between their centres be less than the sum $(r+r')$, but greater than the difference $(r-r')$ of their apparent semi-diameters, a partial interposition will take place (496). The greatest breadth of the obscured parts of the solar disk will in this case be equal to the difference between the sum of the apparent semi-diameters, and the distance between the centres of the two disks, that is, $(r+r') - \text{D}$.

502. **Magnitude of eclipses expressed by digits.**—If the apparent diameter of the obscured object be supposed to be divided into twelve equal parts, each of these parts in reference to eclipses

is called a DIGIT, and the magnitude of an eclipse is expressed by the number of digits contained in the greatest breadth of the obscured part of the disk.

503. **Total solar eclipse.**—To produce a total solar eclipse, it is necessary, 1st, that the apparent diameter of the moon should be equal to or greater than that of the sun, and, 2dly, that the apparent places of their centres should approach each other within a distance not greater than $r-r'$, the difference of their apparent semi-diameters. When these conditions are fulfilled, and so long as they continue to be fulfilled, the eclipse will be total (499).

The greatest value of the apparent semi-diameter of the moon, r, being 1006″, and the least value of that of the sun, r', being 946″, we shall have $r-r'=60''$.

The greatest possible duration, therefore, of a total solar eclipse will be the time necessary for the centre of the moon to gain upon that of the sun $60'' \times 2 = 120''$. But since the mean synodic motion of the moon is at the rate of 30″ per minute, it follows that the duration of a total solar eclipse can never exceed four minutes.

504. **Annular eclipses.** — When the apparent diameter of the moon is less than that of the sun, its disk will not cover that of the sun, even when concentrical with it. In this case, a ring of light would be apparent round the dark disk of the moon, the breadth of which would be equal to the difference of the apparent semi-diameters, as represented at E, *fig.* 81. When the disks are not absolutely concentrical, the distance between their centres being, however, less than the difference of their apparent semi-diameters, the dark disk of the moon will still be within that of the sun, and will appear surrounded by a luminous annulus, but in this case the ring will vary in breadth, the thinnest part being at the point nearest to the moon's centre; and when the distance between the centres is reduced to exact equality with the difference of the apparent semi-diameters, the ring becomes a very thin crescent, the points of the horns of which unite, as represented at D, *fig.* 81.

The greatest breadth of the crescent will be in this case equal to the difference of the apparent diameters of the sun and moon.

The greatest apparent semi-diameter of the sun being 16′ 18″, and the least apparent semi-diameter of the moon being 14′ 44″, the greatest possible breadth of the annulus when the eclipse is centrical will be $r-r'=94''$, which is about the 20th part of the mean apparent diameter of the sun.

The greatest interval during which the eclipse can continue annular is the time necessary for the centre of the moon to move synodically over $94'' \times 2 = 188''$, and, since the mean synodic mo-

tion is at the rate of 30″ per minute, this interval will be about 6·26 minutes.

505. **Solar eclipses can only occur at or near the epoch o. new moons.** — This is evident, because the condition which limits the apparent distance between the centres of the disks to the sum of the apparent semi-diameters, involves the consequence that this distance cannot much exceed 30′, and as the difference of longitudes must be still less than this, it follows that the eclipse can only take place within less than half a degree in apparent distance, and within less than two hours of the epoch of conjunction.

506. **Effects of parallax.** — Since the visual directions of the centres of the disks of the sun and moon vary more or less with the position of the observer upon the earth's surface, the conditions which determine the occurrence of an eclipse, and if it occur, those which determine its character and magnitude, are necessarily different in different parts of the earth. While in some places none of the conditions are fulfilled, and no eclipse occurs, in others an eclipse is witnessed which varies from one place to another in its magnitude, and in some may be total, while it is partial in others.

If the change of position of the observer upon the earth's surface affected the visual directions of the centres of the two disks equally, which would be the case if they were equally distant, or nearly so, no change in the apparent distance between them would be produced, and in that case the eclipse would have the same appearance exactly to all observers in every part of the earth. But the sun being about 400 times more distant than the moon, the visual direction of the centre of its disk is affected by any difference of position of the observers, to an extent 400 times less than that of the moon's centre.

Let S, E, and M, *fig.* 82, represent sections of the sun, earth, and moon, made by the plane which passes through their centres. Let a line P *m s* be drawn, touching the sun and moon, but so that they shall lie on opposite sides of it. It is evident that to an observer at P, the dark disk of the moon would touch that of the sun externally, for the apparent distance between the centres would be measured by the angle S P M, which is equal to the sum S P *s*, the apparent semi-diameter of the sun, and M *p m* that of the moon.

From the point *s* let lines be supposed to be drawn, touching the earth at *p* and *p′*. It is evident that, to an observer situate between P and *p′*, the apparent distance of the centres of the moon and sun would be greater than the sum of their apparent semi-diameters, and they would therefore be separated at the nearest

points of their disks by a space equal to the excess of this distance above the sum of the apparent semi-diameters.

Adopting the signs already used, let r express the apparent semi-diameter of the moon, or nearer disk, r' that of the sun, or more distant disk, and D the apparent distance between their centres, we shall have D greater than $r+r'$ for every point from P to p', and the excess will increase continually from P to p'.

On the other hand, for every point between P and p, D will be less than $r+r'$, and the sun will be eclipsed, the magnitude of the eclipse augmenting gradually from P to p.

The phenomena varying therefore indefinitely with the position of the observer upon the earth, it is necessary, in order to render their prediction practicable, to select a fixed position for which they may be calculated, formulæ being established, and tables prepared, by which the difference between the appearances there and at any proposed place may be computed. The fixed point selected for this purpose is the centre E of the earth.

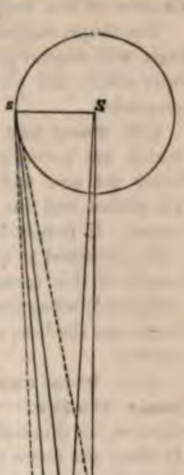


Fig. 81.

The angular distance between the centres of the disks of the sun and moon, as seen from any place, such as P for example, is called their *apparent* distance at that place, and their angular distance, as seen from the centre E of the earth, is called their *true* distance. Thus, S P M is the apparent distance between the centres at P, and S E M is their true distance.

In the actual calculations necessary to supply an exact prediction of the beginning, middle, the end, and the magnitude of a solar eclipse, many particulars must be taken into account, which are not adapted to a work such as the present, but which present no other difficulty than such as attends elaborate arithmetical computation.

507. **Shadow produced by an opaque globe.** — Connected with the phenomena of eclipses and transits are certain properties of shadows.

When a luminous body, radiating light in all directions around it, throws these rays upon an opaque body, that body prevents a portion of the rays from penetrating into the space behind it. That part of the space from which the light is thus excluded by

the interposition of the opaque body, is called in astronomy the SHADOW of that body.

The shape, magnitude, and extent, of the shadow of an opaque body will depend partly on the shape and magnitude of the opaque body itself, and partly on that of the body from which the light proceeds.

508. **Form and dimensions of the shadow.** — In the cases which are actually presented in astronomy, the luminous body being the sun, and the opaque body a planet or satellite, both are globes, and the former of much greater dimensions than the latter. It is easy to show that in such case the shadow will be a cone, projected to a certain distance behind the opaque body. The length of this cone, and the angle formed at its vertex, may be computed, when the real diameters of the sun and the body which forms the shadow, and the distance of the one from the other, are known.

509. **Total and partial solar eclipses explained by the lunar shadow.** — The moon thus projects behind it a conical shadow, the dimensions of which can be ascertained by computation. If when the moon comes between the sun and the earth, which it must do near conjunction, if it be not far removed from the node of its orbit, this shadow will be projected on a part of the hemisphere of the earth which is turned to the sun, provided its length be greater than the moon's distance, as represented in *fig.* 83. In this case the shadow will move over certain points of the surface of the earth lying around the point to which its axis is directed. The light of the sun being altogether intercepted within the limits of the shadow, a total eclipse will take place, the duration of which will be determined by the limits and movement of the shadow thus projected, which is in effect the intersection of the conical shadow of the moon and the earth's surface.

To those parts of the earth which are outside the limits $a\,a'$ of the shadow, but within those $p\,p'$ of the penumbra, a partial eclipse will be exhibited, the magnitude of which will be so much the greater the nearer the place is to the axis of the shadow. All such parts will be more faintly illuminated in proportion to the extent of the sun's disk which is obscured.

510. **Annular eclipses explained by shadow.** — If the length of the shadow be less than the moon's distance from the earth, the vertex not reaching to the earth, no part of the earth's surface can be immersed in the shadow. In that case, a centrical annular eclipse will be exhibited at those points of the earth's surface to which the axis of the shadow is directed. This case is represented in *fig.* 84, where f represents the vertex of the moon's shadow. At all places within the circle upon the earth, of which $a\,a'$ is the

diameter, there will be an annular eclipse, and at the centre of the circle the eclipse will be centrical, the annulus being of uniform

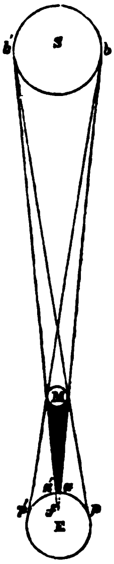


Fig. 83.

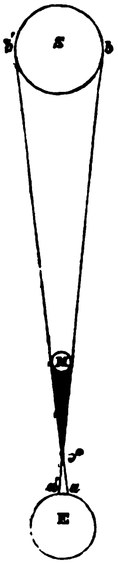


Fig. 84.

breadth. Outside this circle, so far as the penumbra extends, the eclipse will be partial, its magnitude decreasing as the distance of the place from the centre of the circle increases, until at the limit of the penumbra the phenomenon ceases to be exhibited.

511. **Solar ecliptic limits.**—The moon's orbit being inclined to the ecliptic, at an angle of 5°, and, consequently, the distance of the moon's centre from the ecliptic varying in each month from 0° to 5°, while the interposition of the moon between any place on the earth and the sun, requires that the apparent distance of their centres should not exceed the sum of their apparent semi-diameters, which never much exceeds half a degree, it is clear that an eclipse can never happen except when, at the time of conjunction, the apparent distance of the moon's centre from the ecliptic is within that limit, a condition which can only be fulfilled within certain small distances of the moon's nodes.

There is a certain distance from the moon's node *beyond* which a solar eclipse is *impossible*, and a certain lesser distance, *within*

which that phenomenon is *inevitable.* These distances are called the SOLAR ECLIPTIC LIMITS.

512. **Appearances attending total solar eclipses.**—A natural consequence of the diffusion of knowledge is, that while it lessens the vague sense of wonder with which singular phenomena in nature are beheld, it increases the feeling of admiration at the harmonious laws, the development of which renders easily intelligible effects apparently strange and unaccountable. It may be imagined what a sense of astonishment, and even terror, the temporary disappearance of an object like the sun or moon must have produced in an age when the causes of eclipses were known only to the learned. Such phenomena were regarded as precursors of divine vengeance. History informs us that in ancient times armies have been destroyed by the effects of the consternation spread among them by the sudden occurrence of an eclipse of the sun. Commanders who happened to possess some scientific knowledge have taken advantage of it to work upon the credulity of those around them by menacing them with prodigies, the near approach of which they were well aware of, illustrating thus, in a singular and perverted manner, the maxim that knowledge is power.*

The spectacle presented by a total eclipse of the sun is always most imposing. The darkness is sometimes so intense as to render the brighter stars and planets visible. A sudden fall of temperature is sensible in the air. Vegetables and animals comport themselves as they are wont to do after sunset. Flowers close, and birds go to roost. Nevertheless, the darkness is different from the natural nocturnal darkness, and is attended with a certain indescribable unearthly light which throws upon surrounding objects a faint hue, sometimes reddish, and sometimes cadaverously green.

Many interesting narratives have been published by scientific observers, who have been so fortunate as to witness these phenomena.

513. **Baily's beads.**—When the disk of the moon, advancing over that of the sun, has reduced the latter to a thin crescent, it was observed by Mr. Francis Baily, in the solar eclipses of 1836 and 1842, that immediately before the beginning, or after the end of complete obscuration, the crescent appeared as a band of brilliant points separated by dark spaces, so as to give to it the appearance of a string of brilliant "beads." The phenomenon, which has since been frequently re-observed, thence acquired the name of BAILY'S BEADS.

* Columbus is said to have availed himself of his acquaintance with practical astronomy to predict a solar eclipse, and used the prediction as a means of establishing his authority over the crews of his vessels, who showed indications of mutinous disobedience.

Fig. 85.

Fig. 86.

Further observation showed, that before the formation of the "beads" the horns of the crescent were sometimes interrupted and broken by black streaks thrown across them.

These phenomena are roughly sketched in *figs.* 85 and 86.

Figs. 87 to 90 are taken from the original sketches of Mr. Bai representing the progressive disappearance of the beads after t termination of the complete obscuration.

514. **Produced by lunar mountains projected on the su**

Fig. 87.

Fig. 88.

Fig. 89.

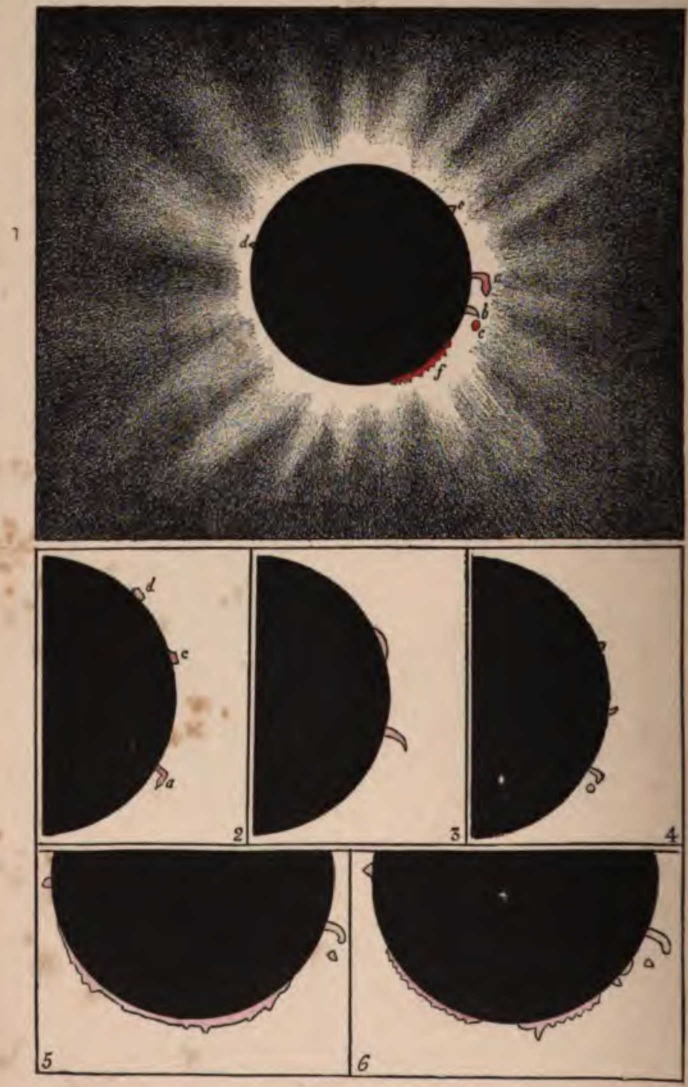
Fig. 90.

disk.—These phenomena arise from the projection of the edge the moon's disk, serrated by numerous inequalities of the surfa approaching so close to the external edge of the sun's disk, that t points of the projections extend to the latter, while the int mediate spaces remain uncovered. This may be very approp ately illustrated by laying the blade of a circular saw, having fin cut teeth, over a white circle of nearly equal diameter upon a bla ground. The white parts between the teeth will appear lik necklace of white pearls.

The fact, that in some cases the beads have not been seen, o

[redacted]

XXII.



TOTAL SOLAR ECLIPSE OF 1851.

Telescopic views of the rose-coloured emanations.

1. Astronomer Royal.
2. Mr. Gray.
3. Mr. Stephenson.
4. Mr. Lassell.
5. Mr. Hind.
6. Mr. Dawes.

seen, appeared in a less conspicuous manner, may be explained by the greater or less prevalence of mountainous masses, on that part of the moon's surface which forms the edge of its disk at different times.

The beads, in general, disappear suddenly, at the moment of the commencement of total obscuration, and reappear on the other side of the lunar disk, with a somewhat startling, instantaneous effect, at the moment the total obscuration ceases.

515. **Flame-like protuberances.**—Immediately after the commencement of the total obscuration, red protuberances, resembling flames, appear to issue from the edge of the moon's disk. These appearances, which were first noticed by Vassenius, on the occasion of the total solar eclipse which was visible at Göttenberg on the 3rd of May, 1733, have been re-observed on the occurrence of every total solar eclipse which has taken place since that time, and constitute one of the most curious and interesting effects attending this class of phenomena.

516. **Solar eclipse of 1851.**—A total eclipse of the sun took place on the 28th of July, 1851, which became a subject of systematic observation by the most eminent astronomers of the present day. A considerable number of English observers, aided by several foreigners, distributed themselves in parties at different points along the path of the shadow, so that the chances of the impediments that might arise from unfavourable conditions of the atmosphere might be diminished. The reports and drawings of these various observers have been presented to the Royal Astronomical Society, and published in their *Transactions*. A detailed description of the phenomena observed on this occasion, together with a few of those witnessed during the recent solar eclipse of the 18th of July, 1860, will give to the reader a sufficient illustration of the numerous peculiarities which are only visible when the sun is totally eclipsed. It is not necessary, therefore, to enter into any detail respecting observations of preceding eclipses.

The Astronomer Royal, with two assistants, Messrs. Dunkin and Humphreys, authorised by the Board of Admiralty, selected certain parts of Norway and Sweden as the most eligible stations. Professor Airy observed at Göttenberg, Sweden, Mr. Dunkin at Christiania, Norway, and Mr. Humphreys at Christianstadt, in the south of Sweden.

517. **Observations of the Astronomer Royal.**—The weather on the whole proved favourable at Göttenberg. We take from the report of the Astronomer Royal the following highly interesting particulars of the progress of the phenomenon.

"The approach of the totality was accompanied with that indescribably mysterious and gloomy appearance of the whole surrounding prospect which

I have seen on a former occasion. A patch of clear blue sky in the zenith became purple-black while I was gazing at it. I took off the higher power, with which I had scrutinised the sun, and put on the lowest power (magnifying about 34 times). With this I saw the mountains of the moon perfectly well. I watched carefully the approach of the moon's limb to the sun's limb, which my graduated dark glass enabled me to see in great perfection; I saw both limbs perfectly well defined to the last, and saw the line becoming narrower and the cusps becoming sharper without any distortion or prolongation of the limbs. I saw the moon's serrated limb advance up to the sun's, and the light of the sun glimmering through the hollows between the mountain peaks, and saw these glimmering spots extinguished one after another in extremely rapid succession, but without any of the appearances which Mr. Baily has described. I saw the sun covered, and immediately slipping off the dark glass, *instantly* saw the appearances represented at *a b c d*, *fig.* 1. Pl. XXII.

"Before alluding more minutely to these, I must advert to the darkness. I have no means of ascertaining whether the darkness really was greater in the eclipse of 1842; I am inclined to think that in the wonderful, and I may say appalling, obscurity, I saw the grey granite hills within sight of Hvaläs more distinctly than the darker country surrounding the Superga, near Turin. But whether because in 1851 the sky was much less clouded than in 1842 (so that the transition was from a more luminous state of sky to a darkness nearly equal in both cases), or from whatever cause, the suddenness of the darkness in 1851 appeared to me much more striking than in 1842. My friends who were on the upper rock, to which the path was very good, had great difficulty in descending. A candle had been lighted in a lantern about a quarter of an hour before the totality; Mr. Hasselgren was unable to read the minutes of the chronometer-face without having the lantern held close to the chronometer.

"The corona was far broader than that which I saw in 1842; roughly speaking, its breadth was little less than the moon's diameter; but its outline was very irregular. I did not remark any beams projecting from it which deserved notice as much more conspicuous than the others; but the whole was beamy, radiated in structure, and terminated (though very indefinitely) in a way which reminded me of the ornament frequently placed round a mariner's compass. Its colour was white, or resembling that of *Venus*. I saw no flickering or unsteadiness of light. It was not separated from the moon by any dark ring, nor had it any annular structure; it looked like a radiating luminous cloud behind the moon.

"The form of the prominences was most remarkable. That which I have marked (*a*) reminded me of a bomerang. Its colour for at least two-thirds of its breadth, from the convexity towards the concavity, was full lake-red, the remainder was nearly white. The most brilliant part of it was the swell farthest from the moon's limb; this was distinctly seen by my friends and myself with the naked eye. I did not measure its height; but judging generally by its proportion to the moon's diameter, it must have been 3'. This estimation perhaps belongs to a later period of the eclipse. The prominence (*b*) was a pale white semicircle based on the moon's limb. That marked (*c*) was a red detached cloud, or balloon, of nearly circular form, separated from the moon's limb by a space (differing in no way from the rest of the corona) of nearly its own breadth. That marked (*d*) was a small triangular or conical red mountain, perhaps a little white in the interior. These were the appearances seen instantly after the formation of the totality.

"I employed myself in an attempt to delineate roughly the appearances on the western limb, and I took a hasty view of the country; and I then examined the moon a second time. I believe (but I did not carefully remark) that the prominences *a b c* had increased in height; but (*d*) had now disappeared, and a new one (*e*) had risen up. It was impossible to see this change without feeling the conviction that the prominences belonged to the sun and not to the moon.

"I again looked round, when I saw a scene of unexpected beauty. The southern part of the sky, as I have said, was covered with uniform white cloud; but in the northern part were detached clouds upon a ground of clear sky. This clear sky was now strongly illuminated, to the height of 30° or 35°, and through almost 90° of azimuth, with rosy red light shining through the intervals between the clouds. I went to the telescope, with the hope that I might be able to make the polarization-observations, (which, as my apparatus was ready to my grasp, might have been done in three or four seconds), when I saw that the *sierra*, or rugged line of projections, shown at (*f*), had arisen. This *sierra* was more brilliant than the other prominences, and its colour was nearly scarlet. The other prominences had perhaps increased in height, but no additional new ones had arisen. The appearance of this *sierra*, nearly in the place where I expected the appearance of the sun, warned me that I ought not now to attempt any other physical observation. In a short time the white sun burst forth, and the corona and every prominence vanished.

"I withdrew from the telescope and looked round. The country seemed, though rapidly, yet half unwillingly, to be recovering its usual cheerfulness. My eye, however, was caught by a duskiness in the south-east, and I immediately perceived that it was the eclipse-shadow in the air travelling away in the direction of the shadow's path. For at least six seconds this shadow remained in sight, far more conspicuous to the eye than I had anticipated."

518. **Observations of Mr. Dunkin at Christiania, Norway, and of Mr. Humphreys at Christianstadt, Sweden.**—Owing to the unfavourable state of the atmosphere, the observations of the other members of the Admiralty party were not so satisfactory as those of its chief. Nevertheless, both observers saw the red prominences, though imperfectly, as compared with the results of the observations of the Astronomer Royal. Baily's beads were seen by Mr. Dunkin, as well before as after the total obscuration. That observer states that—

"About 15 seconds before the beginning of total darkness, the narrow line of the sun broke up into numerous small particles or beads of light. They were of different sizes, some being merely points, while others appeared elongated; their appearance was of intense brilliancy, and the only thing with which I can compare it, is a necklace of diamonds. The effect on the mind at their formation was quite overpowering. I was unprepared for so magnificent a sight.

"At the re-appearance of the sun, the same general appearance of the phenomenon of Baily's beads was exhibited, but the effect on the imagination was not so striking, though the brilliancy of the beads seemed equal to those noticed at the commencement of the totality.

"Three red protuberances were seen; the first was at an angle of 45° from the vertex, on the western limb of the moon, the second at 80°, and the third at 110°. The last-mentioned was most curiously formed, having something of a horned shape, curved in the direction of the lower limb of the moon. Its height was about 1′ 30″, and its breadth at the base, 30″. This prominence was most remarkable from its curved or hooked appearance, and during the interval in which I witnessed it, no change took place in its form. Its colour was pink, or rose, but the shade was not very deep. The other two prominences were similar to each other in size, their height being about 40″, and their breadth at the base, 30″, each tapering to a point at the apex; these prominences, like the preceding, remained at the same altitude during the last minute of total darkness. On the appearance of the first direct ray of light from the solar disk, the protuberances became invisible, no trace of them being perceived after the formation of the beads on the re-appearance of the sun."

With regard to the general darkness at the time of totality, Mr. Dunkin remarks—

"The darkness was not exactly similar to that of night, the outlines of mountains at a distance of at least fifteen miles being faintly visible; but yet I found it difficult to read the title-page of a book ten or twelve inches from the eye. Immediately below me was the Fiord, dotted with its numerous islands. Over this mixture of land and water the effect of the darkness was very peculiar, the water having the colour of deep purple, and the islands a dusky yellow. From my position, every part of the visible sky was covered with cloud, but the density in different parts was unequal; this had the effect of making some portions of the heavens terribly black, while others were comparatively bright. The effect of this great contrast was not easily forgotten."

At Christianstadt, the planets Venus, Mercury, and Jupiter, and the stars Arcturus, and Vega, were visible during the totality of the eclipse.

519. **Observations of Mr. Gray, at Tune, near Sarpsborg, Norway.**—This gentleman also saw Baily's beads, both before and after the total obscuration. He saw four of the red projections, three of which are represented in *fig.* 2. Plate XXII., the fourth resembling *c* and *d* in form, and diametrically opposite to *a* in position on the moon's limb. The apparent height of *a* was estimated at $1\frac{1}{4}'$, and its breadth 62″, but the altitude of this afterwards increased to $1\frac{3}{4}'$. There was a dark shade in the curved portion, which gave it a resemblance to a gas flame. The remainder, however, was rose-red, not uniform, and very pale, like the innermost parts of the petals of a rose. The red prominence opposite to *a* had an apparent altitude of 1′, and a deeper red colour. The prominences *c* and *d* were estimated at about 50″ in size.

During the totality, the light seemed like that of an evening in August in latitude 59°, at an hour and a half after sunset.

520. **Observations of Messrs. Stephenson and Andrews at**

Fredrichsvaarn, Norway.—Baily's beads were seen both before and after the total obscuration. The crescent, before disappearing, was seen as a fine thread of light, which broke up into fragments, and when it re-appeared, it gave the idea of globules of mercury rushing amongst each other along the edge of the moon. In a second or two after the disappearance of the crescent, a rose-coloured flame shot out from the limb of the moon, which in form resembled a sickle, see *fig.* 3. It increased rapidly, and then two other rose-coloured prominences, above and below it, started out, differing in shape, but evidently of the same character. Besides these, there were, as well between them as elsewhere, around the moon's edge, other lurid points and other indistinct lines. The height of the principal prominence was estimated at about the twentieth of the moon's diameter, that is, about $1\frac{1}{2}'$. The chief prominences looked like burning volcanoes, and the lurid points and lines reminded the observers of dull streams of cooling lava.

521. **Observations of Mr. Lassell at Trollhättan Falls, Sweden.**—Having heard the red prominences seen in former total eclipses described as faint appearances, the astonishment of the observer may be imagined when he saw around the dark disk of the moon, after the commencement of total obscuration, prominences of the most brilliant lake colour,—a splendid pink, quite defined and hard, *fig.* 4. They appeared not to be absolutely quiescent. The observer judged from their appearance that they belonged to the sun, and not to the moon.

522. **Observations of Mr. Hind and Mr. Dawes at Rævelsberg, near Engelholm, Sweden.**—Baily's beads were seen, both before and after the total obscuration, in such a manner as to leave no doubt of their cause being that already explained. In five seconds after the commencement of the total obscuration, the corona or glory around the moon's disk was seen. Its colour seemed to be that of tarnished silver, brightest next the moon's limb, and gradually fading to a distance equal to one-third of her diameter, where it became confounded with the general tint of the heavens. Appearances of radiation are mentioned, similar to those described by Professor Airy:—

"On first viewing the sun," says Mr. Hind, "without the dark glass after the commencement of totality, three rose-coloured prominences immediately caught my eye, and others were seen a few seconds later, (*fig.* 5). The largest and most remarkable of them was situate about 5° north of the parallel of declination, on the western limb of the moon; it was straight through two-thirds of its length, but curved like a sabre near the extremity, the concave edge being towards the horizon. The edges were of a full rose pink, the central parts paler, though still pink.

"Twenty seconds, or thereabouts, after the disappearance of the sun, I estimated its length at 45″ of arc, and on attentively watching it towards the

end of totality, I saw it materially lengthened, (probably to 2), the moon having apparently left more and more of it visible as she travelled across the sun. It was always curved, and I did not remark any change of form nor the slightest motion during the time the sun was hidden. I saw this extraordinary prominence *four seconds after the end of totality*, but at this time it appeared detached from the sun's limb, the strong white light of the corona intervening between the limb and the base of the prominence.

"About 10° south of the above object I saw, during the totality, a detached triangular spot of the same rose colour, suspended, as it were, in the light of the corona, which gradually receded from the moon's dark limb, as she moved onwards, and was, therefore, clearly connected with the sun. Its form and position, with respect to the large prominence, continued exactly the same so long as I observed it. On the south limb of the moon appeared a long range of rose-coloured flames, which seemed to be affected with a tremulous motion, though not to any great extent.

"The bright rose-red of the tops of these projections gradually faded towards their bases, and along the moon's limb appeared a bright narrow line of a deep violet tint; not far from the western extremity of this long range of red flames was an isolated prominence, about 40″ in altitude, and another of similar size and form, at an angle of 145° from the north towards the east. The moon was decidedly reddish-purple at the beginning of totality, but the reddish tinge disappeared before its termination, and the disk assumed a dull purple colour. A bright glow, like that of twilight, indicated the position where the sun was about to emerge, and three or four seconds later the beads again formed, this time instantaneously, but less numerous, and even more irregular, than before. In five seconds more the sun reappeared as a very fine crescent on the sudden extinction of the beads."

Mr. Dawes observed the beads, and found all the circumstances attending their appearance such as to leave no doubt as to the truth of the cause generally assigned to them. He observed the corona, a few seconds after the commencement of the totality, and estimated its extreme breadth at half the moon's diameter, the brightness being greatest near the moon's limb, and gradually decreasing outwards. The phenomena of the red protuberances, witnessed by Mr. Dawes, are so clearly and satisfactorily described by him, that we think it best here to give the account of them in his own words: —

"Throughout the whole of the quadrant, from north to east, there was no visible protuberance, the corona being uniform and uninterrupted. Between the east and south points, and at an angle of about 115° from the north point, appeared a large red prominence of a very regular conical form, *fig.* 6. When first seen it might be about 1½′ in altitude from the edge of the moon, but its length diminished as the moon advanced.

"The position of this protuberance may be inaccurate to a few degrees, being more hastily noticed than the others. It was of a deep rose colour, and rather paler near the middle than at the edges.

"Proceeding southward, at about 145° from the north point commenced a low ridge of red prominences, resembling in outline the tops of a very irregular range of hills. The highest of these probably did not exceed 40″

This ridge extended through 50° or 55°, and reached, therefore, to about 197° from the north point, its base being throughout formed by the sharply-defined edge of the moon. The irregularities at the top of the ridge seemed to be permanent, but they certainly appeared to undulate from the west towards the east; probably an atmospheric phenomenon, as the wind was in the west.

"At about 220° commenced another low ridge of the same character, and extending to about 250°, less elevated than the other, and also less irregular in outline, except that at about 225° a very remarkable protuberance rose from it to an altitude of 1½′, or more. The tint of the low ridge was a rather pale pink; the colour of the more elevated prominence was decidedly deeper, and its brightness much more vivid. In form it resembled a *dog's tusk*, the convex side being northwards, and the concave to the south. The apex was somewhat acute. This protuberance and the low ridge connected with it, were observed and estimated in height towards the end of the totality.

"A small double-pointed prominence was noticed at about 255°, and another low one with a broad base, at about 263°. These were also of the rose-coloured tint, but rather paler than the large one at 225°.

"Almost directly preceding, or at 270°, appeared a bluntly triangular pink body, *suspended*, as it were, in the corona. This was separated from the moon's edge when first seen, and the separation increased as the moon advanced. It had the appearance of a large conical protuberance, whose base was hidden by some intervening soft and ill-defined substance, like the upper part of a conical mountain, the lower portion of which was obscured by clouds or thick mist. I think the apex of this object must have been at least 1′ in altitude from the moon's limb when first seen, and more than 1½′ towards the end of total obscuration. Its colour was pink, and I thought it paler in the middle.

"To the north of this, at about 280° or 285°, appeared the most wonderful phenomenon of the whole. A red protuberance, of vivid brightness and very deep tint, arose to a height of, perhaps, 1½′ when first seen, and increased in length to 2′, or more, as the moon's progress revealed it more completely. In shape it somewhat resembled a *Turkish cimeter*, the northern edge being convex, and the southern concave. Towards the apex it bent suddenly to the south, or upwards, as seen in the telescope. Its northern edge was well defined, and of a deeper colour than the rest, especially towards its base. I should call it a *rich carmine*. The southern edge was less distinctly defined, and decidedly paler. It gave me the impression of a somewhat conical protuberance, partly hidden on its southern side by some intervening substance of a soft or flocculent character. The apex of this protuberance was paler than the base, and of a purplish tinge, and it certainly had a flickering motion. Its base was, from first to last, sharply bounded by the edge of the moon. To my great astonishment, this marvellous object *continued visible for about five seconds*, as nearly as I could judge, *after the sun began to reappear*, which took place many degrees to the south of the situation it occupied on the moon's circumference. It then rapidly faded away, *but it did not vanish instantaneously*. From its extraordinary size, curious form, deep colour, and vivid brightness, this protuberance absorbed much of my attention; and I am, therefore, unable to state precisely what changes occurred in the other phenomena towards the end of the total obscuration.

"The arc, from about 283° to the north point, was entirely free from prominences, and also from any roseate tint.

523. **Effects of total obscuration on surrounding objects and scenery.**—Although the different parties of observers scattered over the path of the moon's shadow were not equally fortunate in having a clear unclouded sky, they were all enabled to observe and record the effects of the total obscuration upon the surrounding objects and country. Dr. Robertson of Edinburgh, Dr. Robinson of Armagh, and some others, witnessed the eclipse from an island off the coast of Norway, in lat. 61° 21′, at a point in the path of the axis of the shadow. The precursory phenomena corresponded with those described by other observers. The atmosphere was, however, obscured by clouds, which appeared to rush down in streams from the place of the sun. The sea-fowl flocked to their customary places of rest and shelter in the rocks. The darkness at the moment of total obscuration was sudden, but not absolute; for the clouds had left an open strip of the sky, which assumed a dark lurid orange, which changed to greenish colour in another direction, and shed upon persons and objects a faint and unearthly light. Lamps and candles, seen at fifty or sixty yards' distance, were as visible as in a dark night, and the redness of their light presented a strange contrast with the general green hue of everything around them. "The appearance of the country," says Dr. Robertson, "seen through the lurid opening under the clouds, was most appalling. The distant peaks of the Jostedals and Dovre Field mountains were seen still illuminated by the sun, while we were in utter darkness. Never before had we observed all the lights of heaven and earth so entirely confined to one narrow stripe along the horizon,—never that peculiar greenish hue, and never that appearance of outer darkness in the place of observation, and of excessive distance in the verge of the horizon, caused in this case by the hills there being more highly illuminated as they receded by a less and less eclipsed sun."

Mr. Hind says, that during the obscuration the entire landscape was overspread with an unnatural gloom; persons around him assumed an unearthly, cadaverous aspect; the distant sea appeared of a lurid red; the southern heavens had a sombre purple hue, the place of the sun being indicated only by the CORONA; the northern heavens had an intense violet hue, and appeared very near. On the east and west of the northern meridian, bands of light of a yellowish crimson colour were seen, which gradually faded away into the unnatural purple of the sky at greater altitudes, producing an effect that can never be effaced from the memory, though no description could give a just idea of its awful grandeur.

At several places in Prussia, where the heavens were unclouded

during the total obscuration, a great number of the more conspicuous stars, as well as the planets Jupiter, Venus, and Mercury, were visible. Several flowering plants were observed to close their blossoms, birds which had been previously flying about disappeared, and domestic fowls went to roost.

524. **Solar eclipse of 1860, July 18. — Observations of M. Le Verrier at Tarazona, of M. Goldschmidt at Vittoria, and of M. Secchi at Desierto de las Palmas, Spain.** — The eclipse of the sun on the 18th of July, 1860, was favourably observed in various parts of Spain, by astronomers of all countries. Perhaps on no occasion of a similar nature was a greater interest manifested in organising parties of observers, for the purpose of noting correctly the various phenomena visible only during the totality of a solar eclipse. The Admiralty granted the use of the splendid steamship Himalaya for the conveyance of the British astronomers, and the local authorities in Spain gave every assistance to the expedition.

The results of the observations are not all published, but the important fact has been established that the various phenomena which are only to be seen on these rare occasions are appendages of the sun. Several photographs of the appearances of the sun and moon at different times during the totality, as well as during other phases of the eclipse, have been obtained by Mr. De la Rue and others, on which the prominences are distinctly marked, showing the progress of the motion of the moon in the intervals between the different photographs.

In the absence of published records of English astronomers, we believe it will be instructive to give short extracts from those of M. Le Verrier and M. Goldschmidt of Paris, and M. Secchi of Rome, all of whom were stationed within the zone of totality. These astronomers were favoured with a clear sky during the observations, and the whole of the phenomena usually seen appear to have been observed, with the exception of "Baily's beads." These were, however, seen by other observers.

We consider it better to give M. Le Verrier's account in his own words: —

"I now arrive at the description of the luminous appendages which appeared on the circumference of the lunar and solar disks, and in following the order in which I explored them, that is, commencing at the apparent zenith of the sun, passing down towards the lower part of the disk on its western limb, then ascending by the eastern limb as far as the vertex, and again descending towards the west to the point where the first ray of the sun reappeared. (I speak here of the phenomenon as seen by the naked eye, and not by an inverting telescope.) The first object which I saw in the field of the telescope, after the commencement of the totality, was an isolated cloud entirely separated from the moon's limb by a space equal to its own size, extending

to an altitude of about a minute and a half. The colour of this cloud was of a fine rose mixed with a tinge of violet, and its transparence seemed heightened almost to white by the brilliancy of some of its parts. A little lower to the right, two clouds were lying on each other, the upper cloud being smaller than the lower; these exhibited the greatest inequalities in their intensity of light. The remainder of the western side of the disk, as well as the lower part, presented nothing remarkable, excepting the corona, whose light appeared perfectly white, and of considerable brilliancy; but on the eastern limb, about thirty degrees below the horizontal diameter, I discovered two elevated prominences contiguous to each other. The upper side of each of these protuberances was, like the clouds, vividly tinged with the same rose and violet colour, whilst the opposite side appeared white. I can hardly doubt the form which these prominences presented. As it contrasted in shape with that of the other phenomena which I had previously seen, I verified the jagged appearance of these prominences with great care. On moving my telescope, the high power of which would only allow a small portion of the sun's disk to be seen at once, I recognised a little higher, a third prominence in the shape of a tooth, separated from the other two, but of the same form and colour, and differing only by dimensions more considerable. The remaining part of the disk offered nothing remarkable. On returning to the upper region, I found the two clouds which I have already described, without alteration.

"Twenty seconds before the reappearance of the sun, I directed my attention towards the point at which it was expected. That part of the limb which two minutes previously appeared perfectly white, was now tinged with a narrow thread of a reddish purple colour; but, even as the seconds passed away, this coloured thread gradually increased, and soon formed around the black disk of the moon, to an extent of thirty degrees, a red border of an increasing and definite thickness, the outline being irregular at the upper part. At the same time, the brightness of the portion of the corona, which during the few preceding seconds emerged from under the disk of the moon, increased with such a rapidity, that I was in doubt whether I did not see the limb of the sun. This was no other than the reappearance of a direct ray of light, which in its turn effaced that of the corona, but, however, I was certain of the nature of the phenomena which were passing at the same moment before my eyes, and which may be described in a few words. 1st. The visible part of the emerging surface of the sun, in every direction reaching to an altitude of seven or eight seconds, was covered by a bed of clouds of rose colour, which were seen to increase in density, even as they appeared from behind the disk of the moon. May we believe that the entire surface of the sun is enveloped by them at a low altitude, as it is spread over with faculæ, and that the rose-coloured clouds are emanations from this bed, forming the spots which appear on the disk of the sun? 2nd. The intensity of the light of the corona, which is always perfectly white, varies with great rapidity in the immediate neighbourhood of the solar disk."

Some interesting reflections by M. Le Verrier on the physical constitution of the sun, resulting from a consideration of the various phenomena witnessed by him during the interval of totality at this eclipse, would seem to raise some doubts in his mind of the accuracy of the generally received notion that the sun is composed of a solid opaque nucleus, or globe, invested with two atmospheres,

that which is nearest to the body being non-luminous; while the whole is surrounded by the exterior coating, which is self-luminous, and the source of light and heat. When the exterior covering is broken, the non-luminous matter is supposed to be visible, forming the spots which are continually presenting themselves on the solar disk (240). To this complex constitution, it is now necessary to add another envelope, that which forms the material of the rose-coloured clouds and prominences. M. Le Verrier's remarks on the subject are as follows:—

"Now I fear that the greater part of these envelopes are only matters of fiction; that the sun is simply a luminous body on account of its high temperature, and covered by a continuous bed of rose-coloured matter, the existence of which is now sufficiently proved. The sun, thus formed of a central body, solid or liquid, covered by an atmosphere, is restored to the common law of the constitution of celestial bodies.

"The existence of a bed of rose-coloured matter, partially transparent, covering the whole surface of the sun, is an established fact by the observations made during the time of totality in the present eclipse.

"Observation proves also that this rose-coloured matter is accumulated occasionally on certain points, in quantities more considerable than on others, and as the light of the corresponding part of the sun may be possibly found more or less extinguished, we arrive at a natural explanation of the spots on the sun's surface. These spots will exhibit the most varied forms and appearances, subject to rapid changes, in a similar manner to what has been already observed, provided they are produced by clouds. They will change their positions on the surface of the sun, like clouds on the surface of the earth; and when from their motion the determination of the rotation of the sun on its axis is deduced, we ought to find, as it frequently happens, discordant results.

"The faculæ, or luminous streaks which appear on the surface of the sun, by changing their form and brightness, and by disappearing from certain regions, to appear in others, could be explained by the inequalities and variable density of the atmosphere, and above all, by the illumination of the inclined surface. It may be remarked, that in the neighbourhood of the spots the faculæ are generally most abundant."

The town of Tarazona, near which M. Le Verrier was stationed during the eclipse, is situated on the south side of the river Ebro, at a distance of about ten miles from Tudela. The estimated duration of totality in this part of Spain was about $3^m\ 10^s$.

M. Goldschmidt selected Vittoria as the station at which a favourable state of the sky was probable, and which was also convenient for the observation of the eclipse. The duration of totality at Vittoria was estimated at $3^m\ 0^s$, being about thirty seconds less than at the central line of shadow. The instrument used was a telescope, with an object-glass of four inches aperture, magnifying about 40 times. The corona and rose-coloured prominences were seen distinctly by M. Goldschmidt, drawings of which were made by him. He remarks that—

"The most imposing as well as complicated of these prominences, which I will call the *chandelier*, was grand beyond description. It rose up from the limb, appearing like slender tongues of fire, and of a rose colour; its edges purple and transparent, allowing the interior of the prominence to be seen; in fact, I could see distinctly that this protuberance was hollow. Shortly before the end of the totality, I saw escape from the summits of these rose-coloured and transparent sheaves of light, a slight display in the shape of a fan, which gave to the protuberance a real resemblance to a *chandelier*. Its base, which at the commencement of the totality was noticed very decidedly on the black limb of the moon, became slightly less attached, and the whole took an appearance more ethereal or vapourish; however, I did not lose sight of it for an instant. The jets of light which came from the summits disappeared with the appearance of the first rays of the sun, but it was not so with the protuberance itself, for, an instant before the end of the totality, I saw several small prominences appear lying close to each other on the right of its base, and forming a square, which is the character of toothed prominences; two others of the same height were seen on the left side of its base, when the sun had already appeared, at $2^h\ 55^m$. It should be mentioned that the images in the field of the telescope were inverted.

"The north horn of the solar crescent touched the last of these prominences, four minutes and forty seconds after the reappearance of the sun. The intense light caused me to abandon this interesting observation, for I was not at the time using a coloured glass; however, I am certain that the *chandelier* and the little prominences at its base had not disappeared up to that moment.

"Although I am convinced that the protuberances belong to the sun, nevertheless, I ought to remark that, at the last moment, I was surprised to see the direction of the *chandelier* referred to the centre of the moon, rather than to the centre of the sun. The height of this prominence was estimated about three minutes and a half at the commencement of totality, and four minutes at the end. The second protuberance appeared on the apparent right of this, at a distance of about 35°, being about three minutes and twenty seconds in height, and nearly of the form of the sign of the planet Saturn; this prominence I have called the *hook*. A third, to the right of the two preceding, and at a distance equal to that of the two others, assumed a form of which it is difficult to give an idea; however, I will call it the *tooth*. About eleven degrees to the right of the second protuberance I noticed a fourth, small, and in the form of a square; between this and the third there was situated a rose-coloured cloud, the shape of which was elongated and bent, inclined at an angle of 45° towards the left limb of the moon. This cloud was entirely detached, floating on the corona like a red cloud at sunset. Its centre was elevated above the limb of the moon, about one-half the altitude of the other prominences, or about two minutes. A fifth protuberance also appeared, at the beginning, in the south-east, and was of increased size in the middle of the totality.

"I ought to remark, that all the protuberances which I noticed had a tendency in their forms to describe a curve, the concavity of which was turned from the side of the west."

The eclipse was observed by M. Secchi, of the Collegio Romano, at Desierto de las Palmas, near Oropesa, on the eastern coast of Spain, and very nearly on the central line of totality, the estimated

duration of the total darkness at this station being about $3^m\ 26^s$. M. Secchi remarks: —

"Shortly before the total disappearance of the sun, I noticed the corona through a lightly coloured glass; I removed the glass as soon as the eclipse became total, and I was astonished at its brilliancy, which was sufficient, even at this time, to dazzle the eye; but its brightness visibly diminished, the limb of the sun being surrounded by a purplish corona, terminating in points of the same colour, which soon disappeared: at this time two magnificent protuberances appeared a little above the spot where the sun's limb disappeared. One was conical, with a point rather slender and curved, having the appearance of a flame somewhat agitated. The other was less elevated, but of greater extent; it occupied an arc of four or five degrees of the limb, the summit terminating like teeth of a very fine saw, the upper outline of which was almost parallel to the limb of the moon. These protuberances visibly decreased; their height was estimated at 2½ and 1½ minutes respectively. At the commencement of totality no prominence was visible on the opposite limb of the moon, but about the middle of the eclipse, when the two first had already disappeared, so many luminous points appeared on the other side of the black disk, that I was for a short time embarrassed which to choose for measurement. These brilliant appearances increased in size as fast as the moon glided forward, and I saw with surprise an almost continuous arc of purple light instantaneously formed, composed of small protuberances, in that part of the lunar disk where the reappearance of the sun was expected. What surprised me most was a fine red cloud entirely detached from the protuberances, projected on the white light of the corona, and followed by two others of smaller dimensions. I could not refrain from calling the attention of MM. Aguilar and Cepeda, who observed at my side, to this remarkable phenomenon, the existence of which was verified by these observers. Meanwhile, on the side of the lunar disk where the sun was reappearing, the light of the corona gradually increased, and I saw clearly the line on which, in a marked gradation, the white light of the photosphere mingled with the red points of the prominences; the arc, which was tinged with red, extended at that time to at least 60°. Soon after this the protuberances became invisible, but I still saw the corona with the naked eye during 40 seconds after the reappearance of the sun, the solar light shining like an electric lamp, projecting tremulous shadows.

"These observations have convinced me that the protuberances are connected with the sun, and that it is absurd to assert the contrary."

525. **Evidence of a solar atmosphere.** — Many of the phenomena attending total solar eclipses afford strong corroboratory evidence of the existence of a solar atmosphere, extending to a vast height above the luminous coating of the sun, the probability of which has been already shown (256).

The corona, or bright ray, or glory, surrounding the dark disk of the moon where it covers the sun, is observed to be concentric with the moon only at the moment when the latter is concentric with the sun. In other positions of the moon's disk, it appears to be concentric with the sun. This would be the effect produced by a solar non-luminous atmosphere faintly reflecting the sun's light.

The corona supplies no exact data by which the height of the solar atmosphere thus faintly reflecting light can be ascertained; but Sir J. Herschel thinks, that from the manner in which the diminution of light is manifested on the sun's disk, being by no means sudden on approaching the borders, but extending to some distance within the disk, the height must be not only great in an absolute sense, but must even be a very considerable fraction of the sun's semi-diameter; and this inference is strongly confirmed by the luminous corona surrounding the eclipsed disk.

526. **Probable causes of the red emanations in total solar eclipses.** — It appears to be agreed generally among astronomers that the red emanations above described are solar, and not lunar. From observations made under favourable circumstances in the north of Spain, during the total eclipse of the sun which occurred on the 18th of July, 1860, as well as from photographs of the eclipse successfully taken during the time of totality, conclusive proofs have been recorded that these prominences are strictly solar. If they be admitted then to be solar, it is scarcely possible to imagine them to be solid matter, notwithstanding the apparent constancy of their form in the brief interval during which at any one time they are visible, for the entire duration of their visibility has never yet been so much as four minutes. To admit the possibility of their being solar mountains projecting above the luminous atmosphere surrounding the sun, and rising to the height in the exterior and non-luminous atmosphere forming the corona necessary to explain their appearance, we must suppose their height to amount to nearly a twentieth part of the sun's diameter, that is, to 42,000 miles.

The fact that they are gaseous and not solid matter appears, therefore, to be conclusively established by their enormous magnitude, the great height above the surface of the sun at which they are placed, their faint degree of illumination, and the circumstances of their being sometimes detached at their base from the visible limb of the sun. These circumstances render it probable that these remarkable appearances are produced by cloudy masses of extreme tenuity, supported, and probably produced in an extensive spherical shell of non-luminous gaseous matter, surrounding and rising above the luminous surface of the sun to a great altitude.

When the opinions and reflections of the numerous astronomers who witnessed the phenomena visible during the eclipse of the 18th of July, 1860, are published, we shall doubtless be in a position to settle definitely this important and interesting question. Meanwhile, it is the opinion of M. Le Verrier, who observed the phenomena under favourable circumstances, that it is questionable

whether the received notion of the physical constitution of the sun would account for these red emanations. He suggests that the sun may be simply a luminous body on account of its high temperature, and that it is covered, in some parts in greater density than in others, with a continuous bed of rose-coloured matter. "The sun, thus formed of a central body, and covered by an atmosphere, is restored to the common law of the constitution of celestial bodies." Until, however, the subject is sufficiently discussed by a comparison of the accounts and opinions of other astronomers, it would be merely speculative to come to any conclusion at present.

II. Lunar Eclipses.

527. **Cause of lunar eclipses.**—When the moon is in opposition, its apparent distance from the plane of the ecliptic or its latitude, varying from 0° to upwards of 5°, is at times less than the apparent semi-diameter of the section of the earth's conical shadow, in which case, falling more or less within the shadow, it will be deprived of the sun's light, and will therefore be eclipsed.

The circumstances and conditions attending such a phenomenon depend evidently on the dimensions of the earth's shadow, the magnitude of its section at the moon's distance, and the position of the moon in relation to it.

528. **Conditions which determine lunar eclipses.**—As the earth moves in its orbit round the sun, this conical shadow is therefore constantly projected in a direction contrary to that of the sun. Any body, therefore, which may happen to be in the plane of the ecliptic, or sufficiently near to it, and within this distance of the path of the earth, will be deprived of the sun's light while it is within the limits of the cone. The moon being the only body in the universe which passes within such a distance of the earth, is therefore the only one which can be thus obscured.

The section of the shadow may be regarded as a dark disk, whose apparent semi-diameter varies between 37′ 49″ and 45′ 42″, and the true place of whose centre is a point on the ecliptic 180° behind the centre of the sun. A lunar eclipse is produced by the superposition, partial or total, of this disk on that of the moon, and the circumstances and conditions which determine such an eclipse are investigated upon the principles already explained.

By the solar tables, the apparent position of the centre of the sun, from hour to hour, may be ascertained, and the position of the centre of the section of the shadow may thence be inferred. From the lunar tables, the position of the moon's centre being in like manner determined, the distance between the centres of the section

of the shadow and the moon's disk can be ascertained. When this distance is equal to the sum of the apparent semi-diameters of the moon's disk and the section of the shadow, the eclipse will begin; the moment when the distance is least will be the middle of the eclipse, and the line of greatest obscuration; and when the distance between the centres increasing becomes again equal to the sum of the apparent semi-diameters, the eclipse will terminate. The computation of all these conditions, and the time of their occurrence, presents no other difficulty than those of ordinary arithmetical calculation.

The magnitude of the eclipses is measured, like that of the sun, by the difference between the sum of the semi-diameters and the distance between the centres.

The occurrence of a total eclipse, and the moment of its commencement, if it take place, are determined by the distance between the centre of the shadow and that of the moon becoming equal to the difference between the semi-diameter of the shadow and that of the moon. Thus, a total eclipse will take place if the moon's latitude L in opposition be less than

$$L = S' - s' = (h + h') - (s + s');$$

that is, less than the difference between the sum of the horizontal parallaxes and the sum of the semi-diameters; S being the semi-angle of the conical shadow, S', the apparent semi-diameter of the section of the shadow at the moon's distance, s, s', the apparent semi-diameters, and h, h', the horizontal parallaxes of the sun and moon.

Since the sum of the horizontal parallaxes, even when least, is much greater than the sum of the apparent semi-diameters, even when greatest, a total eclipse of the moon is always possible, provided the centre of the moon approaches near enough to the centre of the shadow, and for the same reason an annular lunar eclipse is impossible.

529. **Lunar ecliptic limits.**—That a lunar eclipse may take place, it is necessary that the moon, when in opposition, should approach the ecliptic within a distance less than the sum of the apparent semi-diameters of the moon and the section of the shadow. Let its latitude in opposition be L', the limiting value of this will be

$$L' = h + h' + s' - s.$$

If the latitude of the moon be less than this (which is the sum of the semi-diameters of the moon and shadow) an eclipse must take place.

But, as in the case of solar eclipses, the quantities composing

this being variable the limit itself is variable. If such values be assigned to the component quantities as to render L′ the greatest possible, we shall obtain the latitude within which an eclipse is possible. If such values be assigned as will render L′ the least possible, we shall obtain the latitude within which an eclipse is inevitable.

530. **Greatest duration of total eclipse.**— The duration of a total eclipse depends on the distance over which the centre of the moon's disk moves relatively to the shadow while passing from the first to the last internal contact. This may vary from 0 to twice the greatest possible distance of the moon's centre from the centre of the shadow at the moment of internal contact, that is, to

$$2\,\text{L}'=2\,(h+h')-2\,(s+s'),$$

and this at its greatest value is,

$$2\text{L}'=2\times(30'\,58'')=61'\,56'';$$

and since the moon's centre moves synodically through half a minute of space in each minute of time, the interval necessary to move over 61′ 56″ will be two hours and four minutes, which is therefore the greatest possible duration of a total lunar eclipse.

531. **Relative number of solar and lunar eclipses.**— It will be evident, from what has been explained, that the frequency of solar is much greater than that of lunar eclipses, since two at least of the former *must*, and five *may*, take place within the year, while not one of the latter may occur. Nevertheless, the number of lunar which are exhibited at *any given place* on the earth is greater than that of solar eclipses, because, although the latter occur with so much greater frequency, they are seen only within particular limits on the earth's surface.

532. **Effects of the earth's penumbra.**— Long before the moon enters within the sides of the cone of the shadow it enters the penumbra, and is partially deprived of the sun's light, so as to render the illumination of its surface sensibly more faint. It might be inferred from this, that the obscuration of the moon is so extremely gradual, that it would be impossible to perceive the limitation of the shadow and penumbra. Nevertheless, such is the splendour of the solar light, that the thinnest crescent of the sun, to which the part of the moon's surface near the edge of the earth's shadow is exposed, produces a degree of illumination which contrasts so strongly with the shadow as to render the boundary of the latter so distinct, that the phenomenon presents one of the most striking evidences of the rotundity of the earth, the form of

the shadow being accurately that which one globe would project upon another.

533. **Effects of refraction of the earth's atmosphere in total eclipses.**—If the earth were not surrounded with an atmosphere capable of refracting the sun's light, the disk of the moon would be absolutely invisible after entering within the edge of the shadow. For the same reason, however, that we continue to see the sun's disk, and receive its rays after it has really descended below the horizon, an observer placed upon the moon, and therefore the surface of the moon itself, must continue to receive the sun's rays after the interposition of the edge of the earth's disk as seen from the moon. This refracted light falling upon the moon after it has entered within the limits of the shadow, produces upon it a peculiar illumination, corresponding in faintness and colour to the rays thus transmitted through the earth's atmosphere.

534. **The lunar disk visible during total obscuration.**—When the moon's limb first enters the shadow, the contrast and glare of the part of the disk still enlightened by the direct rays of the sun, render the eye insensible to the more feeble illumination produced upon the eclipsed part of the disk by the refracted rays. As, however, the eclipse proceeds, and the magnitude of the part of the disk directly enlightened decreases, the eye, partly relieved from the excessive glare, begins to perceive very faintly the eclipsed limb, which is nevertheless visible from the beginning in a telescope, in which it appears with a dark grey hue. When the entire disk has passed into the shadow, it becomes distinctly visible, showing a gradation of tints from a bluish or greenish on the outside to a gradually increasing red, which, further in, changes to a colour resembling that of incandescent iron when at a dull red heat. As the lunar disk approaches the centre of the shadow, this red line is spread all over it. Its illumination in this position is sometimes so strong as to throw a sensible shadow, and to render distinctly visible in the telescope the lineaments of light and shadow upon its surface.

These effects are altogether similar to the succession of tints developed in our atmosphere at sunset, and arise, in fact, from the same cause, operating, however, with a twofold intensity. The solar rays traversing twice the thickness of air, the blue and green lights are more effectually absorbed, and a still more intense red is imparted to the tints transmitted. Without pursuing these consequences further here, the reader will find no difficulty in tracing them in the effects of sunset and of sunrise, and of evening and morning twilight.

III. Eclipses, Transits, and Occultations of the Jovian System.

535. **The motions of Jupiter and his satellites, as seen from the earth, exhibit from time to time all the effects of interposition.**— Let J J′, *fig.* 91. represent the planet, J f J′ its conical shadow, $s s'$ the sun, E and E′ the positions of the earth when the planet is in quadrature, in which position the shadow J f J′ is presented with least obliquity to the visual line, and therefore least foreshortened, and most distinctly seen. Let $b\,b'\,d'\,d$ represent the orbit of one of the satellites the plane of which coincides nearly with that of the planet's orbit, and, for the purposes of the present illustration, the latter may be considered as coinciding with the ecliptic without producing sensible error.

Fig. 91.

From E suppose the visual lines E J and E J′ to be drawn, meeting the path of the satellite at d and g, and at a and b', and, in like manner, let the corresponding visual lines from E′ meet it at d' and g', and at a' and b'. Let c and c' be the points where the path of the satellite crosses the limits of the shadow, and h and h' the points where it crosses the extreme solar rays which pass along those limits.

If l express the length J f of the shadow, d the distance of the planet from the sun in semi-diameters of the planet, and r and r' the semi-diameters of the sun and the planet respectively, we shall have

$$l = d \times \frac{r'}{r - r'},$$

by which formula the length of the shadow is found to be 1247 semi-diameters of the planet. Now, since the distance of the most remote satellite is not so much as 27 semi-diameters of the planet (406), and since the orbits of the satellites are almost exactly in the plane of the orbit of the planet, it is evident that

they will necessarily pass through the shadow, and almost through its axis, every revolution, and the lengths of their paths in the shadow will be very little less than the diameter of the planet.

The fourth satellite, in extremely rare cases, presents an exception to this, passing through opposition without entering the shadow. In general, however, it may be considered that all the satellites in opposition pass through the shadow.

536. **Effects of interposition.**—The planet and satellites exhibit, from time to time, four different effects of interposition.

537. 1st. **Eclipses of the satellites.**—These take place when the satellites pass through the shadow behind the planet. Their entrance into the shadow, called the *immersion*, is marked by their nearly sudden extinction. Their passage out of the shadow, called their *emersion*, is manifested by their being suddenly relighted.

538. 2nd. **Eclipses of the planet by the satellites.**—When the satellites, at the periods of their conjunctions, pass between the lines s J and s' J$'$, their shadows are projected on the surface of the planet in the same manner as the shadow of the moon is projected on the earth in a solar eclipse, and in this case the shadow may be seen moving across the disk of the planet, in a direction parallel to its belts, as a small, round, and intensely black spot.

539. 3rd. **Occultations of the satellites by the planets.**—When a satellite, passing behind the planet, is between the tangents E J a' and E J$'$ b', drawn from the earth, it is concealed from the observer on the earth by the interposition of the body of the planet. It disappears on one side of the planet's disk, and reappears on the other side, having passed over that part of its orbit which is included between the tangents. This phenomenon is called an occultation of the satellite.

540. 4th. **Transits of the satellites over the planet.**—When a satellite, being between the earth and planet, passes between the tangents E J and E J$'$, drawn from the earth to the planet, its disk is projected on that of the planet, and it may be seen passing across, as a small brown spot, brighter or darker than the ground on which it is projected, according as it is projected on a dark or bright belt. The entrance of the satellite upon the disk, and its departure from it, are denominated its *ingress* and *egress*.

541. **Phenomena predicted in Nautical Almanac.**—The times of the occurrence of all these several phenomena are calculated and predicted with the greatest precision, and may be found registered in the Nautical Almanac, with the diagrams for each month to aid the observer. The mean time, at Greenwich, of the eclipses of the satellites is there accurately given, so that if the time at which any of them are observed to occur in any other place be

noted, the difference of such local time and that registered in the Almanac will give the longitude of the place east or west of the meridian of Greenwich. The observations of the other phenomena of the satellites of Jupiter cannot be made with sufficient accuracy, for the determination of differences of longitude.

542. **Motion of light discovered, and its velocity measured, by means of these eclipses.**—Soon after the invention of the telescope, Roemer, an eminent Danish astronomer, engaged in a series of observations, the object of which was the discovery of the exact time of the revolution of one of these bodies round Jupiter. The mode in which he proposed to investigate this was, by observing the successive eclipses of the satellite, and noticing the time between them.

Now if it were possible to observe accurately the moment at which the satellite would, after each revolution, either enter the shadow, or emerge from it, the interval of time between these events would enable us to calculate exactly the velocity and motion of the satellite. It was, then, in this manner that Roemer proposed to ascertain the motion of the satellite. But, in order to obtain this estimate with the greatest possible precision, he proposed to continue his observations for several months.

Let us, then, suppose that we have observed the time which has elapsed between two successive eclipses, and that this time is, for example, forty-three hours. We ought to expect that the eclipse would recur after the lapse of every successive period of forty-three hours.

Imagine, then, a table to be computed in which we shall calculate and register beforehand the sidereal time at which every successive eclipse of the satellite for twelve months to come shall occur, and let us conceive that the earth is at E, at the commencement of our observations: we shall then, as Roemer did, observe the times at which the eclipses occur, and compare them with the corresponding times registered in the table.

Let the earth, therefore, at the commencement of these observations, be supposed at E, *fig.* 65, where it is nearest to Jupiter. When the earth has moved to E″, it will be found that the occurrence of the eclipse is *a little later* than the time registered in the table.

As the earth moves from E″ towards E‴, the actual occurrence of the eclipse is more and more retarded beyond the time of its computed occurrence, until at E‴, in conjunction, it is found to occur about sixteen minutes later than the calculated time.

By observations such as these, Roemer was struck with the fact that his predictions of the eclipses proved in every case to be wrong. It would at first occur to him that this discrepancy might arise

from some errors of his observations; but, if such were the case, it might be expected that the result would betray that kind of irregularity which is always the character of such errors. Thus it would be expected that the predicted time would sometimes be later, and sometimes earlier, than the observed time, and that it would be later and earlier to an irregular extent. On the contrary, it was observed, that while the earth moved from E to E‴, the observed time was continually later than the predicted time, and, moreover, that the interval by which it was later continually and regularly increased. This was an effect, then, too regular and consistent to be supposed to arise from the casual errors of observation; it must have its origin in some physical cause of a regular kind.

The attention of Roemer being thus attracted to the question, he determined to pursue the investigation by continuing to observe the eclipses. Time accordingly rolled on, and the earth, transporting the astronomer with it, moved from E‴ to E′.

It was now found, that though the time observed was later than the computed time, it was not so much so as at E‴; and as the earth again approached opposition, the difference became less and less, until on arriving at E, the position of opposition, the observed eclipse agreed in time exactly with the computation.

From this course of observation it became apparent that the lateness of the eclipse depended altogether on the increased distance of the earth from Jupiter. The greater that distance, the later was the occurrence of the eclipse as apparent to the observers, and on calculating the change of distance, it was found that the delay of the eclipse was exactly proportional to the increase of the earth's distance from the place where the eclipse occurred. Thus when the earth was at E‴, the eclipse was observed sixteen minutes, or about 1000 seconds later than when the earth was at E. The diameter of the orbit of the earth, E E‴, measuring about two hundred millions of miles, it appeared that that distance produced a delay of a thousand seconds, which was at the rate of two hundred thousand miles per second. It appeared, then, that for every two hundred thousand miles that the earth's distance from Jupiter was increased, the observation of the eclipse was delayed one second.

Such were the facts which presented themselves to Roemer. How were they to be explained? It would be absurd to suppose that the actual occurrence of the eclipse was delayed by the increased distance of the earth from Jupiter. These phenomena depend only on the motion of the satellite and the position of Jupiter's shadow, and have nothing to do with, and can have no dependence on, the position or motion of the earth, yet unquestionably the time they

appear to occur to an observer upon the earth, has a dependence on the distance of the earth from Jupiter.

To solve this difficulty, the happy idea occurred to Roemer that the moment at which we see the extinction of the satellite by its entrance into the shadow is not, in any case, the very moment at which that event takes place, but sometime afterward, viz. such an interval as is sufficient for the light which left the satellite just before its extinction to reach the eye. Viewing the matter thus, it will be apparent that the more distant the earth is from the satellite, the longer will be the interval between the extinction of the satellite and the arrival of the last portion of light which left it at the earth; but the moment of the extinction of the satellite is that of the commencement of the eclipse, and the moment of the arrival of the light at the earth is the moment the commencement of the eclipse is observed.

Thus Roemer, with the greatest felicity and success, explained the discrepancy between the calculated and the observed times of the eclipses; but he saw that these circumstances placed a great discovery at his hand. In short, it was apparent that light is propagated through space with a certain definite speed, and that the circumstances we have just explained supply the means of measuring that velocity.

We have shown that the eclipse of the satellite is delayed one second more for every two hundred thousand miles that the earth's distance from Jupiter is increased, the reason of which obviously is, that light takes one second to move over that space; hence it is apparent that the velocity of light is at the rate, in round numbers, of two hundred thousand miles per second.

By more exact observation and calculation the velocity is found to be 184,000 miles per second, the time taken in crossing the earth's orbit being $16^{m}\ 35^{s}\cdot 6$.

543. **Eclipses of Saturn's satellites not observable.**— Owing to the obliquity of the orbits of the Saturnian satellites to that of the primary, eclipses only take place at or near the equinoxes of the planet, the satellites revolving nearly in the common plane of the equator and the ring. When they do take place, these eclipses are so difficult of observation as to be practically useless for the determination of longitudes, and have, consequently, received but little attention.

IV. Transits of the Inferior Planets.

544. **Conditions which determine a transit.** — When an inferior planet, being in inferior conjunction, has a less latitude or distance from the ecliptic than the sun's semi-diameter, it will be less distant from the sun's centre than such semi-diameter, and will

therefore be within the sun's disk. In this case, the planet being between the earth and sun, its dark hemisphere being turned towards the earth, it will appear projected upon the sun's disk as an intensely black round spot. The apparent motion of the planet being then retrograde, it will appear to move across the disk of the sun from east to west in a line sensibly parallel to the ecliptic.

Such a phenomenon is called a TRANSIT, and as it can only take place with planets which pass between the earth and sun, it is limited to the inferior planets.

545. **Intervals of the occurrence of transits.** — The transits of Mercury and Venus are phenomena of rare occurrence, especially those of Venus, and they are separated by very unequal intervals. The following are the dates of the successive transits of Mercury from 1845 to the end of the present century: —

1845 - - - -	May 8.
1848 - - - -	Nov. 9.
1861 - - - -	Nov. 11.
1868 - - - -	Nov. 4.
1878 - - - -	May 6.

Those of Venus occur only at intervals of 8, 122, 8, 105, 8, 122, &c. years; the last occurred in 1769. Two only will take place in the present century — on the 8th of December, 1874, and on the 6th of December, 1882.

546. **The sun's distance determined by the transit of Venus.** — The transits of Venus have acquired immense interest and importance, from the circumstance of their supplying data by which the sun's distance from the earth can be determined with far greater precision than by any other known method. The transits of Mercury would supply like data, but owing to the greater distance of that planet from the earth when in inferior conjunction, the conditions affecting the data are not nearly so favourable as those supplied by Venus.

The transit of Venus on the 3rd of June, 1769, was considered of sufficient importance for sending out an astronomical expedition to Otaheite, in the Pacific Ocean, for the purpose of obtaining observations of this rare phenomenon at a distant part of the globe, which would supply the necessary data, in conjunction with those found from observations in other localities, for ascertaining the amount of the sun's parallax. This expedition was under the command of the celebrated Captain Cook. The French, Russian, and other governments also fitted out expeditions in the most liberal manner, which were sent to various parts of the globe.

On a comparison of all the observations, it was found that they gave $8''\cdot5776$ as the value of the sun's horizontal parallax, or $17''\cdot1552$ as the angle which the earth's diameter subtends at the *sun*. (See Appendix, 807.)

The details of this celebrated problem of the determination of the sun's parallax, by observations of the transit of Venus across the solar disk, are much too complicated, and involve calculations too long and intricate to be explained here, the limited extent of this volume forbidding explanations which require much space in their elucidation.

V. Occultations.

547. **Occultation defined.** — When any celestial object, the sun excepted, is concealed by the interposition of another, it is said to be OCCULTED, and the phenomenon is called an OCCULTATION.

Strictly speaking, a solar eclipse is an occultation of the sun by the moon, but usage has given to it, by exception, the name of an eclipse.

548. **Occultations by the moon.** — The phenomena of this class which possess greatest astronomical interest are those of stars and planets by the moon. That body, measuring about half a degree in diameter, moves in her monthly course so as to occult every object on the firmament which is included in a zone extending to a quarter of a degree at each side of the apparent path of her centre. All the stars whose places lie in this zone are successively occulted, and disappearances and reappearances of the more conspicuous ones, as well as those of the planets which may be found within the limits of the same zone, present some of the most striking effects which are witnessed by observers.

The astronomical amateur will find in the Nautical Almanac a table in which all the principal occultations, both of stars and planets, are predicted.

The disappearance takes place always at the limb of the moon, which is presented in the direction of its motion.

From the epoch of full moon to that of new moon the moon moves with the enlightened edge foremost, and from new moon to full moon with the dark edge foremost. During the former interval, therefore, the objects occulted disappear at the enlightened edge, and reappear at the dark edge, and during the latter period they disappear at the dark, and reappear at the enlightened edge.

The disappearances and reappearances when the moon is a crescent are especially remarkable. If the disappearance take place at the convex edge, notice of its approach is given by the visible proximity of the star, which, at the moment of contact, is suddenly extinguished. Its reappearance is more startling, for it seems to be suddenly lighted up at a point of the firmament nearly half a degree from the concave edge of the crescent. If the disappearance take place at the dark edge it is much more striking, the star appearing to "go out" of itself at a point of the sky where nothing interferes with it.

When stars, however, are of less magnitude than the fifth, the overpowering light of the moon makes the star invisible before the occultation takes place at the enlightened edge. At the re-appearance the same effect is produced, the star before becoming visible is frequently some distance from the bright limb of the moon.

The moon's horizontal parallax amounting to nearly twice its diameter, the part of the firmament on which it is projected and which is its apparent place, differs at different parts of the earth. In different latitudes the moon, therefore, in the course of the month appears to traverse different zones of the firmament, and consequently to occult different stars. Stars which are occulted in certain latitudes are not occulted at all at others, and of those which are occulted, the durations of the occultation and the moments and places of disappearance and reappearance are different.

To render this more intelligible, let N S, *fig.* 92, represent the earth, N being its north, and S its south pole. Let m m' represent the moon, and m* and m' * the direction of a star which is occulted by it. It must be observed that the distance of the star being practically infinite compared with the diameter of the moon, the lines m* and m' * are parallel. Let these lines be supposed to be continued to meet the earth at l and l'. Let similar lines, parallel to these, be imagined to be drawn through all points of a section of the moon made by a plane at right angles to the direction of the star passing through the moon's centre. Such lines would form a cylindrical surface, the base of which would be the section of the moon, and it would be intersected by the surface of the earth, a portion of which would be included within it, one-half of which is represented by the darkly shaded part of the earth between l and l'. It is clear that the star will be occulted by the moon to all observers situated within this space.

Fig. 92.

While this cylindrical space is carried by the moon's orbital motion from west to east, the surface of the earth included between the parallels of latitude l n and l' n', is also carried from west to east, but much more rapidly, by the diurnal rotation,

so that the places between these parallels are continually overtaking the cylindrical space which limits the occultation.

It is evident that beyond $l\ n$ and $l'\ n'$, which are called the "limiting parallels," no occultation can take place. At l and l' the star is seen just to touch the moon's limb without being occulted, but within those limits it will be occulted. The middle parallel, $o\ o'$ between the limited parallels, is that at which a central occultation is seen, and where therefore the duration is greatest. The occultation *may* be seen from any place upon the earth which lies within the shaded zone, and *will* be seen provided the phenomenon occur during the night, and that the star at the time be above the horizon at such an altitude as to render the event observable.

In the Nautical Almanac these "limiting parallels" for every conspicuous occultation are tabulated, as well as the data necessary to enable an observer at any proposed latitude to ascertain previously whether any particular occultation will be observable.

549. **Determination of longitudes by lunar occultations.** — In common with all phenomena which can be exactly predicted, and whose manifestation is instantaneous, occultations of stars by the moon are eminently useful for the exact determination of longitudes. The frequency of their occurrence greatly increases their utility in this respect, and, although, for nautical purposes, the observer cannot always choose his time of observation, and therefore cannot be left dependent on them, they come in aid of the lunar method as verifications; and for geographical purposes on land, are among the best means which science has supplied. The times of the disappearance and reappearance as given in the Nautical Almanac being only approximate, it is necessary to compare the times as observed at any particular station with that observed at another station, as at Greenwich for example, from which the difference of longitude of the two places is inferred.

550. **Occultations indicate the presence or absence of an atmosphere around the occulting body.** — When a star is occulted by the disk of the moon or planet, its brightness, previously to its disappearance, would be more or less dimmed by the atmosphere surrounding such object, if it existed. Such a gradual decrease of brightness previously to disappearance, as well as a like increase of brightness after reappearance, has been observed in occultations by the disks of planets, but never by the disk of the moon.

It is hence inferred that the planets have, and the moon has not, an atmosphere.

It might be objected, that the lunar atmosphere may not have sufficient density to produce any sensible diminution of brightness.

Another test has, however, been found in the effect which the refraction of an atmosphere would have in decreasing the duration of an occultation. No such decrease being observed, it is inferred that no atmosphere exists around the moon.

551. **Singular visibility of a star after the commencement of occultation.** — Some observers, of sufficient weight and authority to command general confidence, have occasionally witnessed a phenomenon in occultations known as the projection of a star on the disk of the moon. According to them, it sometimes happens that after the occulted star has apparently passed behind the limb of the moon it continues to be seen, and even for some seconds, notwithstanding the actual interposition of the body of the moon. If this be not an optical illusion, and if the visual rays actually come straight to the observer, they must pass through a deep fissure in the moon. Such a supposition is compatible only with the rare, and apparently fortuitous, occurrence of the phenomenon.

The general opinion of astronomers, however, is that the phenomenon of the projection of a star on the moon's disk can be explained in most cases by the general principles of irradiation. This singular visibility of a star after the commencement of the occultation, would obviously be a direct consequence of irradiation, if we assume that the image of the moon's limb is sometimes spuriously enlarged by some optical defect in the instrument or the observer, and that the image of the star is therefore seen through this imperfect limb, being really a false impression on the visual organs of the observer, created by the above defect.

In the *Memoirs of the Royal Astronomical Society*, vol. xxviii., the Astronomer Royal has treated this subject at some length, and has collected every reliable instance of recorded projection of a star on the moon's disk. From 1699 to 1857, seventy-four cases have been noticed by astronomers of various countries, and of the highest authority. Mr. Airy remarks that, "It is to be conceived that every luminous point of the moon's disk is accompanied with a system of rings; and therefore, that the aggregate of light produced by the aggregate of all the luminous points of the moon's disk, is not a luminous image bounded by a sharp outline at what we consider the geometrical outline of the image, but that the geometrical outline is fringed by a band of illumination, produced by the interlacing and superposition (not interference) of all the systems of rings; and as the light from the different sources is actually superposed and aggregated, it is certain that there must be a considerable quantity of light external to the geometrical limb; and when, with a very fine telescope, we see the moon's limb very sharply defined, and apparently surrounded by immediate darkness, we do in reality see it erroneously. Probably some operation of the mind, under the

conviction that the outline of light ought to fall in a given curve, acts on the animal faculty of sensation so as to incapacitate the visual organs from perceiving the fainter light beyond that curve." Mr. Airy considers that his explanations of these curious phenomena bring them under the general category of irradiation. But it is a kind of irradiation which exists at one time but not at another, which is seen at the same place by one observer, but is unnoticed by others, and that sometimes it remains apparently constant for, at least, several seconds of time, and sometimes varies from instant to instant. These phenomena, however, form an interesting subject for future investigation.

552. **Suggested application of lunar occultations to resolve double stars.** — Sir J. Herschel thinks that these occultations would supply means of ascertaining the double character of some stars, the individuals suspected to compose which are too close together to be divided by any telescope. He thinks, nevertheless, that they might disappear in perceptible succession behind the edge of the moon's disk. It does not seem to be easy to conceive how such an effect can be expected in a case where the most powerful telescopes have failed to resolve the stars.

553. **Occultations by Saturn's rings.** — In the case of stars occulted by Saturn's rings, a reappearance and second disappearance may be seen in the open space between the ring and the planet. It has been affirmed also, that a momentary reappearance of a star, in the space which intervenes between the rings, has been witnessed. This observation does not, however, seem to have been repeated, notwithstanding the recent improvements in the telescope, and the increased number of observers. The passage of the planet, in a favourable phase of the ring, through the neighbourhood of the milky way, which is so thickly strewed with stars, would afford an opportunity of testing this, and might also supply decisive evidence, positive or negative, upon the question of the existence of more than two concentric rings. If other black streaks seen upon the surface of the ring be, like the principal one, real openings between a multiple system of rings, the stars sprinkled in such countless numbers over the regions of the galaxy, and the adjacent parts of the firmament, would be seen to flash between ring and ring, as the planet passes before them. Such observations, however, would require in the telescope the very highest attainable degree of optical perfection.

CHAPTER XVIII.

COMETS.

I. Cometary Orbits.

554. **Prescience of the astronomer.**—For the civil and political historian the past alone has existence—the present he rarely apprehends; the future never. To the historian of science it is permitted, however, to penetrate the depths of past and future with equal clearness and certainty: facts to come are to him as present and not unfrequently more assured than facts which are passed. Although this clear perception of causes and consequences characterises the whole domain of physical science, and clothes the natural philosopher with powers denied to the political and moral inquirer, yet foreknowledge is eminently the privilege of the astronomer. Nature has raised the curtain of futurity, and displayed before him the succession of her decrees, so far as they affect the physical universe, for countless ages to come; and the revelations of which she has made him the instrument, are supported and verified by a never-ceasing train of predictions fulfilled. He "shows us the things which will be hereafter," not obscurely shadowed out in figures and in parables, as must necessarily be the case with other revelations, but attended with the most minute precision of time, place, and circumstance. He converts the hours as they roll into an ever-present miracle, in attestation of those laws which his Creator through him has unfolded; the sun cannot rise—the moon cannot wane—a star cannot twinkle in the firmament, without bearing witness to the truth of his prophetic records. It has pleased the "Lord and Governor" of the world, in His inscrutable wisdom, to baffle our inquiries into the nature and proximate cause of that wonderful faculty of intellect—that image of his own essence which he has conferred upon us; nay, the springs and wheelwork of animal and vegetable vitality, are concealed from our view by an impenetrable veil, and the pride of philosophy is humbled by the spectacle of the physiologist bending in fruitless ardour over the dissection of the human brain, and peering in equally unproductive inquiry over the gambols of an animalcule. But how nobly is the darkness which envelopes metaphysical inquiries compensated by the flood of light which is shed upon the physical creation! *There* all is harmony, and order, and majesty, and beauty. From the chaos of social and political

phenomena exhibited in human records—phenomena unconnected to our imperfect vision by any discoverable law, a war of passions and prejudices, governed by no apparent purpose, tending to no apparent end, and setting all intelligible order at defiance—how soothing and yet how elevating it is to turn to the splendid spectacle which offers itself to the habitual contemplation of the astronomer! How favourable to the development of all the best and highest feelings of the soul are such objects! the only passion they inspire being the love of truth, and the chiefest pleasure of their votaries arising from excursions through the imposing scenery of the universe—scenery on a scale of grandeur and magnificence compared with which whatever we are accustomed to call sublimity on our planet dwindles into ridiculous insignificancy. Most justly has it been said, that nature has implanted in our bosoms a craving after the discovery of truth, and assuredly that glorious instinct is never more irresistibly awakened than when our notice is directed to what is going on in the heavens. "Quoniam eadem Natura cupiditatem ingenuit hominibus veri inveniendi, quod facillime apparet, cum vacui curis, etiam quid in cœlo fiat, scire avemus; his initiis inducti omnia vera diligimus; id est, fidelia, simplicia, constantia; tum vana, falsa, fallentia odimus." *

555. **Strikingly illustrated by cometary discovery.**—Such reflections are awakened by every branch of the science which now engages us, but by none so strongly as by the history of cometary discovery. No where can be found so marvellous a series of phenomena foretold. The interval between the prediction and its fulfilment has sometimes exceeded the limits of human life, and one generation has bequeathed its predictions to another, which has been filled with astonishment and admiration at witnessing their literal accomplishment.

556. **Motion of comets explained by gravitation.**—In the vast framework of the theory of gravitation constructed by Newton, places were provided for the arrangement and exposition not only of all the astronomical phenomena which the observation of all preceding generations had supplied, but also for a far greater mass which the more fertile and active research of the generations which succeeded him have furnished. By this theory, as we have seen, all the known planetary motions were explained, and planets previously unseen were felt by their effects, their places ascertained, and the telescope of the observer guided to them.

But transcendently the greatest triumph of this celebrated theory was the exposition it supplied of the physical laws which govern the motions of comets as distinguished from those which prevail among the planets.

* Cicero: *De Finibus Bonorum et Malorum*, ii. 14.

557. **Conditions imposed on the orbits of bodies which are subject to the attraction of gravitation.**—It is proved in the propositions demonstrated in the first book of Newton's Principia, which propositions form in substance the ground-work of the entire theory of gravitation, that a body which is under the influence of a central force, the intensity of which decreases as the square of the distance increases, must move in one or other of the curves known to geometers as the "CONIC SECTIONS," being those which are formed by the intersection of the surface of a cone by a plane, and that the centre of attraction must be in the FOCUS of the curve; and in order to prove that such curves are compatible with no other law of attraction, and may therefore be taken as conclusive evidence of the existence of this law, it is further demonstrated that whenever a body is observed to move round a centre of attraction in any one of these curves, that centre being its focus, the law of the attraction will be that of gravitation; that is to say, its intensity will vary in the inverse proportion of the square of the distance of the moving body from the centre of force.

Fig. 93.

Subject to these limitations, however, a body may move round the sun in any orbit, at any distance, in any plane, and in any direction whatever. It may describe an ellipse of any excentricity, from a perfect circle to the most elongated oval. This ellipse may be in any plane, from that of the ecliptic to one at right angles to it, and the body may move in such ellipses either in the same direction as the earth or in the contrary direction. Or the body thus subject to solar attraction may move in a parabola with its point of perihelion at any distance whatever from the sun, either grazing its very surface

or sweeping beyond the orbit of Neptune, or, it may sweep round the sun in an hyperbola, entering and leaving the system in two divergent directions.

To render these explanations, which are of the greatest interest and importance in relation to the subject of comets, more clearly understood, we have represented in *fig.* 93, the forms of a very excentric ellipse, *a b a′ b′*, a parabola *a p p′*, and an hyperbola *a h h′*, having *s* as their common focus, and it will be convenient to explain in the first instance the relative magnitude of some important lines and distances connected with these orbits.

558. **Elliptic orbits.**—Ellipses or ovals vary without limit, in their excentricity. A circle is regarded as an ellipse whose excentricity is nothing. The orbits of the planets generally are ellipses, but having excentricities so small that, if described on a large scale in their proper proportions on paper, they would be distinguishable from circles only by measuring accurately the dimensions taken in different directions, and thus ascertaining that they are longer in a certain direction than in another at right angles to it. A very excentric and oblong ellipse is delineated in *fig.* 93, of which *a a′* is the major axis. The focus being *s*, the perihelion distance is *s a*, and the aphelion distance is *s a′*, the mean distance *a* being *a c*, or half the major axis.

If a body move in a very excentric ellipse, such as that represented in *fig.* 93, whose plane coincides exactly or nearly with the common plane of the planetary orbits, it may intersect the orbits of several or all of the planets, as it is represented to do in the figure, although its mean distance from the sun may be less than the mean distance of several of those which it thus intersects. The aphelion distance of such a body may, therefore, greatly exceed that of any planet; while its mean distance may be less than that of the more distant planets.

559. **Parabolic orbits.**—The form of a parabolic orbit having the same perihelion distance as the elliptic orbit is represented at *a p p′*, in *fig.* 93. This orbit consists of two indefinite branches, similar in form, which unite at perihelion *a*. Departing from this point on opposite sides of the axis *a a′*, their curvature regularly and rapidly decreases, being equal at equal distances from perihelion. The two branches have a constant tendency to assume the direction and form of two straight lines parallel to the axis *a a′*. To actual parallelism, and still less to convergence, these branches, however, never attain, and consequently they can never reunite. They extend, like parallel straight lines, to an unlimited distance without ever reuniting, but assuming directions when the distance from the focus bears a high ratio to the perihelion distance, which are practically undistinguishable from parallelism.

One parabolic orbit differs from another in its perihelion distance. The less this distance is, the less will be the separation at a given distance from *s* between the parallel directions to which the indefinite branches *p p′* tend. This distance may have any magnitude. The body in its perihelion may graze the surface of the sun, or may pass at a distance from it greater than that of the most remote of the planets, so that, although it be subject to solar attraction, it would in that case never enter within the limits of the solar system at all.

A body moving in such an orbit, therefore, would not make, like one which moves in an ellipse, a succession of revolutions round the sun; nor can the term periodic time be applied at all to its motion. It enters the system in some definite direction, such as *p′ p*, as indicated by the arrow, from an indefinite distance. Arriving within the sensible influence of solar gravitation, the effects of this attraction are manifested in the curvation of its path, which gradually increases as its distance from the sun decreases, until it arrives at perihelion, where the attractive force, and consequently the curvature, attain their maxima. The extreme velocity which the body attains at this point produces, in virtue of the inertia of the moving mass, a centrifugal force, which counteracts the gravitation, and the body, after passing perihelion, begins to retreat; the solar gravitation and the curvature of its path decreasing together, until it issues from the system in a direction *p p′*, as indicated by the arrows, which is nearly a straight line, and parallel to that in which it entered. In such an orbit a body therefore visits the system but once. It enters in a certain direction from an indefinite distance, and, passing through its perihelion, issues in a parallel direction, passing to an unlimited distance, never to return.

560. **Hyperbolic orbits.**—This class of orbits, like the parabolas, consist of two indefinite branches, which unite at perihelion, which at equal distances from perihelion have equal curvatures, and which, as the distance from perihelion increases, approach indefinitely in direction and form to straight lines, but, unlike the parabolic orbits, the straight lines to whose direction the two branches approximate are divergent and not parallel.

Such an orbit having the same perihelion distance as the ellipse and parabola, is represented by *a h h′*.

In the *fig.* 93, the orbits circular, elliptic, parabolic, and hyperbolic, are necessarily represented as being all in the same plane. It must, however, be understood, that, so far as any conditions are imposed upon them by the law of gravitation, they may severally be in any planes whatever, inclined each to the other at any angles whatever from 0° to 90°, with their mutual intersections or lines of nodes in any directions whatever, and that the bodies

may move in these several orbits, in any directions, how opposed soever to each other.

561. **Planets observe in their motions order not exacted by the law of gravitation.**—When the theory of gravitation was first propounded by its illustrious author, no other bodies, save the planets and satellites then discovered, were known to move under the influence of such a central attraction. These bodies, however, supplied no example of the play of that celebrated theory in its full latitude. They obeyed, it is true, its laws, but they did much more. They displayed a degree of harmony and order far exceeding what the law of gravitation exacted. Permitted by that law to move in any of the three classes of conic sections, their paths were exclusively elliptical; permitted to move in ellipses infinitely various in their excentricities, they moved exclusively in such as differed almost insensibly from circles; permitted to move at distances subordinated to no regular law, they moved in a series of orbits at distances increasing in a regular progression; permitted to move at all conceivable angles with the plane of the ecliptic, their paths are inclined to it at angles limited in general to a few degrees; permitted, in fine, to move in either direction, they all agreed in moving in the direction in which the earth moves in its annual course.

Accordance so wonderful and order so admirable, could not be fortuitous, and, not being enjoined by the conditions of the law of gravitation, must either be ascribed to the immediate dictates of the Omnipotent Architect of the universe above all general laws, or to some general laws superinduced upon gravitation, which had escaped the sagacity of the discoverer of that principle. If the former supposition were adopted, some bodies, different in their physical characters from the planets, primary and secondary, and playing different parts and fulfilling different functions in the economy of the universe, might still be found, which would illustrate the play of gravitation in its full latitude, sweeping round the sun in all forms of orbit excentric, parabolic, and hyperbolic, in all planes, at all distances, and indifferently in both directions. If the latter supposition were accepted, then no other orbit, save ellipses of small excentricity, with planes coinciding nearly with that of the ecliptic would be physically possible.

562. **Comets observe no such order in their motions.**—The theory of gravitation had not long been promulgated, nor as yet been generally accepted, when the means of its further verification were sought in the motion of comets. Hitherto these bodies had been regarded as exceptional and abnormal, and as being exempt altogether from the operation of the law and order which prevailed in a manner so striking among the members of the solar

system. So little attention had been given to comets that it had not been certainly ascertained whether they were to be classed as meteoric or cosmical phenomena; whether their theatre was the regions of the atmosphere, or the vast spaces in which the great bodies of the universe move. Their apparent positions in the heavens on various occasions of the appearances of the most conspicuous of them had nevertheless been from time to time for some centuries observed and recorded with such a degree of precision as the existing state of astronomical science permitted; and even when their places were not astronomically ascertained, the date of their appearance was generally preserved in the historic records, and in many cases the constellations through which they passed were indicated, so that the means of obtaining at least a rude approximation to their position in the firmament were thus supplied.

563. **They move in conic sections, with the sun for the focus.** — Such observations, vague, scattered, and inexact as they were, supplied, however, data by which, in several cases, it was possible to compute the real motion of these bodies through space, their positions in relation to the sun, the earth, and the planets, and the paths they followed in moving through the system, with sufficiently approximate accuracy to conclude with certainty that they were one or other of the conic sections, the place of the sun being the focus.

This was sufficient to bring these bodies under the general operation of the attraction of gravitation.

It still remained, however, to determine more exactly the specific character of these orbits. Are they ellipses more or less excentric? or parabolas? or hyperbolas? — Any of the three classes of orbits would, as has been shown, be equally compatible with the law of gravitation.

564. **Difficulty of ascertaining in what species of conic section a comet moves.**— It might be supposed that the same course of observation as that by which the orbit of a planet is traced would be applicable equally to comets. Many circumstances, however, attend this latter class of bodies, which render such observations impossible, and compel the astronomer to resort to other means to determine their orbits.

A spectator stationed upon the earth keeps within his view each of the other planets of the system throughout nearly the whole of its course. Indeed, there is no part of the orbit of any planet at which, *at some time or other*, it may not be seen from the earth. Every point of the path of each planet can therefore be observed; and, although without waiting for such observation, its course might be determined, yet it is material here to attend to the fact, that the whole orbit may be submitted to direct obser-

vation. The different planets, also, present peculiar features by which each may be distinguished. Thus, as has been explained, they are observed to be spherical bodies of various magnitudes. Their surfaces are marked by peculiar modes of light and shade, which, although variable and shifting, still, in each case, possess some prevailing and permanent characters by which the identity of the object may be established, even were there no other means of determining it.

Unlike planets, comets do not present to us those individual characters above-mentioned, by which their identity may be determined. None of them have been satisfactorily ascertained to be spherical bodies, nor indeed to have any definite shape. It is certain that many of them possess no solid matter, but are masses consisting of some nearly transparent substances; others are so surrounded with this apparently vaporous matter, that it is impossible, by any means of observation which we possess, to discover whether this vapour enshrouds within it any solid mass. The same vapour which thus envelopes the body (if such there be within it) also conceals from us its features and individual character. Even the limits of the vapour itself, if vapour it be, are subject to great change in each individual comet. Within a few days they are sometimes observed to increase or diminish some hundred-fold. A comet appearing at distant intervals presents, therefore, no very obvious means of recognition. A like extent of surrounding vapour would evidently be a fallible test of identity; and not less inconclusive would it be to infer diversity from a different extent of nebulosity.

If a comet, like a planet, revolved round the sun in an orbit nearly circular, it might be seen in every part of its path, and its identity might thus be established independently of any peculiar characters in its appearance. But such is not the course which comets are observed to take.

In general a comet is visible only throughout an arc of its orbit, which extends to a certain limited distance on each side of its perihelion. It first becomes apparent at some point of its path, such as g, g', or g'', *fig.* 93; it approaches the sun and disappears after it passes a corresponding point g, g', or g'', in departing from the sun. The arc of its orbit in which alone it is visible would therefore be $g\ a\ g$, $g'\ a\ g'$, or $g''\ a\ g''$.

If this arc, extending on either side of perihelion, could always be observed with the same precision as are the planetary orbits, it would be possible, by the properties of the conic sections, to determine not only the general character of the orbit, whether it be an ellipse, or parabola, or an hyperbola, but even to ascertain the individual curve of the one kind or the other in which the comet

moves, so that the course it followed before it became visible, as well as that which it pursues after it ceases to be visible, would be as certainly and precisely known as if it could be traced by direct observation throughout its entire orbit.

565. **Hyperbolic and parabolic comets not periodic.** — If it be ascertained that the arc in which the comet moves while it is visible is part of an hyperbola, such as *g a g*, it will be inferred that the comet coming from some indefinitely distant region of the universe, has entered the system in a certain direction, *h′ h*, which can be inferred from the visible arc *g a g*, and that it must depart to another indefinitely distant region of the universe following the direction *h h′*, which is also ascertained from the visible arc *g a g*.

If, on the other hand, it be ascertained that the visible arc, such as *g′ a g′*, be part of a parabola, then, in like manner by the properties of that curve, it will follow that it entered the system coming from an indefinitely distant region of the universe in a certain direction, *p′ p*, which can be inferred from the visible arc *g′ a g′*, and that after it ceases to be visible, it will issue from the system in another determinate direction, *p p′*, parallel to that by which it entered.

The comet, in neither of these cases, would have a periodic character. It would be analogous to one of those occasional meteors which are seen to shoot across the firmament never again to reappear. The body, arriving from some distant region, and coming, as would appear, fortuitously within the solar attraction, is drawn from its course into the hyperbolic or parabolic path, which it is seen to pursue, and escapes from the solar attraction, issuing from the system never to return. The phenomenon would in each case be occasional, and, in a certain sense, accidental, and the body could not be said properly to belong to the system. So far as relates to the comet itself, the phenomenon would consist in a change of the direction of its course through the universe, operated by the temporary action of solar gravitation upon it.

566. **Elliptic comets periodic like the planets.** — But the case is very different, the tie between the comet and the system much more intimate, and the interest and physical importance of the body transcendently greater when the arc, such as *g″ a g″*, proves to be part of an ellipse. In that case, the invisible part of the orbit being inferred from the visible, the major axis *a a′* would be known. The comet would possess the periodic character, making successive revolutions like the planets, and returning to perihelion *a* after the lapse of its proper periodic time, which could be inferred by the harmonic law from the magnitude of its major axis.

Such a body will then not be, like those which follow hyperbolic

or parabolic paths, an occasional visitor to the system, connected with it by no permanent relation, and subject to solar gravitation only accidentally and temporarily. It would, on the contrary, be as permanent, if not as strictly regular, a member of the system as any of the planets, though invested, as will presently appear, with an extremely different physical character.

It will therefore be easily conceived with what profound interest comets were regarded before the theory of gravitation had been yet firmly established or generally accepted, and while it was, so to speak, upon its trial. These bodies were, in fact, looked for as the witnesses whose testimony must decide its fate.

567. **Difficulties attending the analysis of cometary motions.**—Difficulties, however, which seemed almost insurmountable, opposed themselves to the satisfactory and conclusive analysis of their motions. Many causes rendered the observations upon their apparent places few in number and deficient in precision. The arcs $g\ a\ g$, $g'\ a\ g'$, and $g''\ a\ g''$, of the three classes of orbit in any of which they might move without any violation of the law of gravitation, were very nearly coincident in the neighbourhood of the place of perihelion a. It was, for example, in almost all the cases which presented themselves, possible to conceive three different curves, an excentric ellipse, such as $a\ b\ a'\ b'$, a parabola, such as $p'\ p\ a$, and an hyperbola, such as $h'\ h\ a$, so related that the arcs $g\ a\ g$, $g'\ a\ g'$, and $g''\ a\ g''$, would not deviate one from another to an extent exceeding the errors inevitable in cometary observations. Thus any one of the three curves within the limits of the visible path of the comet might with equal fidelity represent its course. In such cases, therefore, it was impossible to infer, from the observations alone, whether the comet belonged to the class of hyperbolic or parabolic bodies, which have no periodic character, or to the elliptic, which has.

568. **Periodicity alone proves the elliptic character.**—The character of periodicity itself, which belongs exclusively to elliptic orbits, supplied the means of surmounting this difficulty. If any observed comet have an elliptic motion, it must return to perihelion after completing its revolution, and it must have been visible on former returns to that position. Not only ought it to be expected, therefore, that such a comet would re-appear in future after absences of equal duration (depending on its periodic time), but that its previous returns to perihelion would be found by searching among the recorded appearances of such objects for any, the dates of whose appearance might correspond with the supposed period, and whose apparent motions, if observed, might indicate a real motion in an orbit, identical or nearly so with that of the comet in question.

If the motion of such a body were not affected by any other force except the solar attraction, it would re-appear after each successive revolution at exactly the same point; would follow, while visible, exactly the same arc $g'' a g''$; would move in the same plane, inclined at the same angle to the ecliptic, the nodes retaining the same places; and would arrive at its perihelion at exactly the same point a, and after exactly equal intervals.

Now, although the disturbing actions of the planets near which it might pass, in departing from and returning to the sun, must be expected to be much more considerable than when one planet acts upon another, as well because of the extreme comparative lightness of the comet, as of the great excentricity of its orbit, which sometimes actually or nearly intersects the paths of several planets, and especially those of the larger ones, yet still such planetary attractions are *only* disturbances, and cannot be supposed to efface that character which the orbit receives from the predominant force of the immense mass of the sun. While therefore we may be prepared for the possibility, and even the probability, that the same periodic comet on the occasion of its successive re-appearances, may follow a path $g'' a g''$ in passing to and from its perihelion, differing to some extent from that which it had followed on previous appearances, yet in the main such differences cannot, except in rare and exceptional cases, be very considerable, and for the same reason the intervals between its successive periods, though they may differ, cannot be subject to any very great variation.

569. **Periodicity, combined with the identity of the paths while visible, establishes identity.**—If then, on examining the various comets whose appearances have been recorded, and whose places while visible have been observed, and on computing from the apparent places the arc of the orbit through which they moved, it be found that two or more of them, while visible, moved in the same path, the presumption will be that these were the same body re-appearing after having completed its motion in an elliptic orbit; nor should this presumption of identity be hastily rejected because of the existence of any discrepancies between the observed paths, or any inequality of the intervals between its successive re-appearances, so long as such discrepancies can fairly be ascribed to the possible disturbances produced by planets which the comet might have encountered in its path.

570. **Many comets recorded—few observed.**—Many comets, however, have been *recorded*, but not *observed*. Historians have mentioned, and even described, their appearances, and in some cases have indicated the chief constellations through which such bodies passed, although no observations of their apparent places have been transmitted by which any close approximation to their

actual paths could be made. Nevertheless, even in these cases, some clue to their identification is supplied. The intervals between their appearances alone is a highly probable test of identity. Thus if comets were regularly recorded to have appeared at intervals of fifty years (no circumstance affording evidence of the diversity of these objects), they might be assumed, with a high degree of probability, to be the successive returns of an elliptic comet having that interval as its period.

571. **Classification of the cometary orbits.**— The appearances of about 400 comets had been recorded in the annals of various countries before the end of the seventeenth century, the epoch signalised by the discoveries and researches of Newton. In most cases, however, the only circumstance recorded was the appearance of the object, accompanied in many instances with details bearing evident marks of exaggeration respecting its magnitude, form, and splendour. In some few cases, the constellations through which the object passed successively, with the necessary dates, are mentioned, and in some, fewer still, observations of a rough kind have been handed down. From such scanty data, eagerly sought for in the works preserved in different countries, more especially from astronomical records preserved in China from the earliest ages, sufficient materials have been collected for the computation, with more or less approximation, of the elements of the orbits of about sixty of the 400 comets above mentioned.

Since the time of Newton, Halley, and their contemporaries, observers have been more active, and have had the command of instruments of considerable and constantly increasing power; so that every comet which has been visible from the northern hemisphere of the earth since that time, has been observed with continually increasing precision, and data have been in all cases obtained, by which the elements of the orbits have been calculated. Since the year 1700, accordingly, more than 160 have been observed, the elements of the orbits of which have been ascertained with great precision.

It appears, therefore, that of the entire number of comets which have appeared in the firmament, the orbits of upwards of 220 have been computed. Of this number about forty have been ascertained, some conclusively, others with more or less probability, to revolve in elliptic orbits.

Several have passed through the system in hyperbolas, and consequently will not visit it again, unless they be thrown into other orbits by some disturbing force.

The remainder, and by far the greatest number, have passed through the system either in parabolic orbits, or in ellipses of such

extreme excentricity as to be undistinguishable from parabolas by any data supplied by the observations.

II. Elliptic Comets revolving within the Orbit of Saturn.

572. **Encke's comet.**—In 1818, a comet was observed at Marseilles, on the 26th of November, by M. Pons. In the following January, its path being calculated, M. Arago immediately recognised it as identical with one which had appeared in 1805. Subsequently, M. Encke of Berlin succeeded in calculating its entire orbit—inferring the invisible from the visible part—and found that its period was about twelve hundred days. This calculation was verified by the fact of its return in 1822, since which time the comet has gone by the name of *Encke's comet*, and returned regularly.

It may be asked, How it could have happened that a comet which made its revolution in a period so short as three years and a quarter, should not have been observed until so recent an epoch as 1818? This is explained by the fact that the comet is so small, and its light so feeble even when in the most favourable position, that it can only be seen with the aid of the telescope, and not even with this, except under certain conditions which are not fulfilled on the occasion of every perihelion passage. Nevertheless, the comet was observed on three former occasions, and the general elements of its path recorded, although its elliptic, and consequently periodic character, was not recognised.

On comparing, however, the elements then observed with those of the comet now ascertained, no doubt can be entertained of their identity.

It appears, that, excepting the oval form of the orbit, the motion of this body differs in nothing from that of a planet whose mean distance from the sun is that of the nearest of the planetoids. Its excentricity is such, however, that when in perihelion it is within the orbit of Mercury, and when in aphelion it is outside the most distant of the planetoids, and at a distance from the sun equal to four-fifths of that of Jupiter.

573. **Indications of the effects of a resisting medium.**—A fact altogether anomalous in the motions of the bodies of the solar system, and indicating a consequence of the highest physical importance, has been disclosed in the observation of the motion of this comet. It has been found that its periodic time, and consequently its mean distance, undergoes a slow, gradual, and apparently regular decrease. The decrease is small, but not at all uncertain. It amounted to about a day in ten revolutions, a quantity which could not by any means be placed to the account

either of errors of observation or of calculation; and, besides, this increase is incessant, whereas errors would affect the result sometimes one way and sometimes the other. The period of the comet between 1786 and 1795 was $1208\frac{1}{3}$ days; between 1795 and 1805 it was $1207\frac{9}{10}$ days; between 1805 and 1819 it was $1207\frac{4}{10}$ days; and between 1845 and 1855, it had decreased to $1205\frac{1}{4}$ days.

The magnitude of the orbit thus constantly decreasing (for the cube of its greater axis must decrease in the same proportion as the square of the period), the actual path followed by the comet must be a sort of elliptic spiral, the successive coils of which are very close together, every successive revolution bringing the comet nearer and nearer to the sun.

Such a motion could not arise from the disturbing action of the planets. These forces have been taken strictly into account in the computation of the ephemerides of the comet, and there is still found this residual phenomenon, which cannot be placed to their account, but which is exactly the effect which would arise from any physical agency by which the tangential motion of the comet would be feebly but constantly resisted. Such an agency, by diminishing the tangential velocity, would give increased efficacy to the solar attraction, and consequently, increased curvature to the comet's path; so that, after each revolution, it would revolve at a less distance from the centre of attraction.

574. **The luminiferous ether would produce such an effect.** — It is evident that a resisting medium, such as the luminiferous ether (O. 216) is assumed to be in the hypothesis which forms the basis of the undulatory theory of light, would produce just such a phenemenon, and, accordingly the motion of this comet is regarded as a strong evidence tending to convert that hypothetical fluid into a real physical agent.

It remains to be seen whether a like phenomenon will be developed in the motion of other periodic comets. The discovery of these bodies, and the observation of their motions, are as yet too recent to enable astronomers, notwithstanding their greatly multiplied number, to pronounce decisively upon it.

575. **Comets would ultimately fall into the sun.**—If the existence of this resisting medium should be established by its observed effects on comets in general, it will follow that, after the lapse of a certain time (many ages, it is true, but still a definite interval), the comets will be successively absorbed by the sun, unless, as is not improbable, they should be previously vaporised by their near approach to the solar fires, and should thus be incorporated with his atmosphere.*

* In the efforts by which the human mind labours after truth, it is curious to observe how often that desired object is stumbled upon by acci-

576. **Why like effects are not manifested in the motion of the planets.**—It may be asked, If the existence of a resisting medium be admitted, whether the same ultimate fate must not await the planets? To this inquiry it may be answered that, within the limits of past astronomical record, the ethereal medium, if it exist, has had no sensible effect on the motion of any planet. That it might have a perceptible effect upon comets, and yet not upon planets, will not be surprising, if the extreme lightness of the comets compared with their bulk be considered. The effect in the two cases may be compared to that of the atmosphere upon a piece of swan's-down and upon a leaden bullet moving through it. It is certain that whatever may be the nature of this resisting medium, it will not, for many hundred years to come, produce the slightest perceptible effect upon the motions of the planets.

577. **Corrected estimate of the mass of Mercury.**—The masses of comets in general are, as will be explained, incomparably smaller than those of the smallest of the planets; so much so, indeed, as to bear no appreciable ratio to them. A consequence of this is, that while the effects of their attraction upon the planets are altogether insensible, the disturbing effects of the masses of the planets upon them are very considerable. These disturbances, being proportional to the disturbing masses, may then be used as measures of the latter, just as the movement of the pith-ball in the balance of torsion supplies a measure of the physical forces to which that instrument is applied.

Encke's comet near its perihelion passes near the orbit of Mer-

dent, or arrived at by reasoning which is false. One of Newton's conjectures respecting comets was, that they are "the aliment by which suns are sustained;" and he therefore concluded that these bodies were in a state of progressive decline upon the suns, round which they respectively swept; and that into these suns they from time to time fell. This opinion appears to have been cherished by Newton to the latest hours of his life: he not only consigned it to his immortal writings; but, at the age of eighty-three, a conversation took place between him and his nephew on this subject, which has come down to us. "I cannot say," said Newton, "when the comet of 1680 will fall into the sun: possibly after five or six revolutions; but whenever that time shall arrive, the heat of the sun will be raised by it to such a point, that our globe will be burnt, and all the animals upon it will perish. The new stars observed by Hipparchus, Tycho, and Kepler, must have proceeded from such a cause, for it is impossible otherwise to explain their sudden splendour." His nephew then asked him, "Why, when he stated in his writings that comets would fall into the sun, did he not also state those vast fires they must produce, as he supposed they had done in the stars?" —"Because," replied the old man, "the conflagrations of the sun concern us a little more directly. I have said, however," added he, smiling, "enough to enable the world to collect my opinion."

cury; and when that planet at the epoch of its perihelion happens to be near the same point, a considerable and measureable disturbance is manifested in the comet's motion, which being observed supplies a measure of the planet's mass.

This combination of the motions of the planet and comet took place under very favourable circumstances, on the occasion of the perihelion passage of the comet in 1838, the result of which, according to the calculations of Professor Encke, was the discovery of an error of large amount in the previous estimates of the mass of the planet. After making every allowance for other planetary attracttions, and for the effects of the resisting medium, the existence of which it appears necessary to admit, it was inferred that the mass assigned to Mercury by Laplace was too great in the proportion of 12 to 7.

This question is still under examination, and every succeeding perihelion passage of the comet will increase the data by which its more exact solution, may be accomplished.

578. **Biela's comet.**—On the 28th of February, 1826, M. Biela, an Austrian officer, observed in Bohemia a comet, which was seen at Marseilles at about the same time by M. Gambart. The path which it pursued, was observed to be similar to that of comets which had appeared in 1772 and 1806. Finally, it was found that this body moved round the sun in an oval orbit, and that the time of its revolution was about 6 years and 8 months. It has since returned at its predicted times, and has been adopted as a member of our system, under the name of Biela's comet.

Biela's comet moves in an orbit whose plane is inclined at a small angle to those of the planets. It is but slightly oval, the length being to the breadth in the proportion of about four to three. When nearest to the sun, its distance is a little less than that of the earth; and when most remote from the sun, its distance somewhat exceeds that of Jupiter. Thus it ranges through the solar system, between the orbits of Jupiter and the earth.

This comet was observed in 1772 and 1806, but the elliptic form of its orbit was not discovered at that epoch. From the observations made in 1826, the ellipticity of the orbit was determined, and its return to perihelion in 1832 successfully predicted. Owing to the extreme faintness and unfavourable position of the comet in 1838, it escaped observation; but in 1846 and 1852 its return was observed by several astronomers. However, on its arrival at perihelion in May, 1859, the comet was so completely lost in the rays of the sun, that astronomers who had the assistance of the most powerful telescopes, were unable to discover it, notwithstanding three separate computers had calculated ephemerides of its position

in the heavens, which agreed sufficiently well with each other to warrant their adoption in the search for the comet.

579. **Possibility of the collision of Biela's comet with the earth.**—One of the points at which the orbit of Biela's comet intersects the plane of the ecliptic, is at a distance from the earth's orbit less than the sum of the semi-diameters of the earth and the comet. It follows, therefore (496) that if the comet should arrive at this point at the same moment at which the earth passes through the point of its orbit which is nearest to it, a portion of the globe of the earth must penetrate the comet.

It was estimated on the occasion of the perihelion passage of this comet in 1832, that the semi-diameter of the comet (that body being nearly globular, and having no perceptible tail) was 21,000 miles, while the distance of the point at which its centre passed through the plane of the ecliptic, on the 29th of October in that year, from the path of the earth, was only 18,600 miles. If the centre of the earth happened to have been at the point of its orbit nearest to the centre of the comet on that day, the distance between the centres of the two bodies would have been only 18,600 miles, while the semi-diameter of the comet was 21,000 miles; and the semi-diameter of the earth being in round numbers 4000 miles, it would follow that in such a contingency the earth would have plunged into the comet to a depth of 6400 miles, a depth exceeding three-fourths of the earth's diameter.

The possibility of such a catastrophe having been rumoured, great popular alarm was excited before the expected return of the comet in 1832. It was, however, shown that on the 29th of October, the earth would be about five millions of miles from the point of danger, and that on the arrival of the earth at that point the comet would have moved to a still greater distance.

580. **Resolution of Biela's comet into two.**—One of the most extraordinary phenomena of which the history of astronomy affords any example, attended the appearance of this comet in 1846. It was on that occasion seen to resolve itself into two distinct comets, which, from the latter end of December, 1845, to the epoch of its disappearance in April, 1846, moved in distinct and independent orbits. The paths of these two bodies were in such optical juxtaposition that both were always seen together in the field of view of the telescope, and the greatest visual angle between their centres did not amount at any time to 10′, the variation of that angle arising principally from the change of direction of the visual line, relatively to the line joining their centres, and to the change of the comet's distance from the earth.

M. Plantamour, director of the Observatory of Geneva, calculated the orbits of these two comets, considered as independent

bodies; and found that the real distance between their centres was, subject to but little variation while visible, about thirty-nine semi-diameters of the earth, or two-thirds of the moon's distance. The comets moved on thus, side by side, without manifesting any reciprocal disturbing action; a circumstance no way surprising, considering the infinitely minute masses of such bodies.

581. **Changes of appearance attending the separation.** — The original comet was apparently a globular mass of nebulous matter, semi-transparent at its very centre, no appearance of a tail being discoverable. After the separation, both comets had short tails, parallel in their direction, and at right angles to the line joining their centres; both had nuclei. From the day of their separation the original comet decreased, and the companion increased in brightness until (on the 10th of February) they were sensibly equal. After this the companion still increased in brightness, and from the 14th to the 16th was not only greatly superior in brightness to the original, but had a sharp and starlike nucleus compared to a diamond spark. The change of brightness was now reversed, the original comet recovering its superiority, and acquiring on the 18th the same appearance as the companion had from the 14th to the 16th. After this the companion gradually faded away, and disappeared previously to the final disappearance of the original comet on the 22nd of April.

It was observed also that a thin luminous line or arc was thrown across the space which separated the centres of the two nuclei, especially when one or the other had attained its greatest brightness, the arc appearing to emanate from that which for the moment was the brighter.

After the disappearance of the companion, the original comet threw out three faint tails, forming angles of 120° with each other, one of which was directed to the place which had been occupied by the companion.

It is suspected that the faint comet which was observed by Professor Secchi to precede Biela's comet in 1852, may have been the companion thus separated from it, and if so, the separation must be permanent, the distance between the parts being greater than that which separates the earth from the sun.

582. **Faye's comet.** — On the 22nd of November, 1843, M. Faye, at that time assistant-astronomer at the Paris Observatory, discovered a comet, the path of which soon appeared to be incompatible with the parabolic character. Dr. Goldschmidt, of Göttingen, showed that it moved in an ellipse of very limited dimensions, with a period of 7½ years. It was immediately observed as being extraordinary, that, notwithstanding the fre-

quent returns to perihelion which such a period would infer, its previous appearances had not been recorded. M. Faye replied by showing that the aphelion of the orbit passed very near to the path of Jupiter, and that it was possible that the violent action of the great mass of that planet, in such close proximity with the comparatively light mass of the comet, might have thrown the latter body into its present orbit, its former path being either a parabola or an ellipse, with such elements as to prevent the comet from coming within visible distance. M. Faye supported these observations by reference to a more ancient comet, which we shall presently notice, to which a like incident is supposed with much probability, if not certainty, to have occurred.

583. **Re-appearance in 1850–1 calculated by M. Le Verrier.** — The observations which had been made in 1843, at several observatories, but more especially those made by M. Struve at Pulkowa, who continued to observe the comet long after it had ceased to be observed elsewhere, supplied to M. Le Verrier the data necessary for the calculation of its motion in the interval between its perihelion in 1843, and its expected re-appearance in 1850–1, subject to the disturbing action of the planets, and predicted its succeeding perihelion for the 3rd of April, 1851.

Aided by the formulæ of M. Le Verrier, Lieutenant Stratford calculated a provisional ephemeris in 1850, by which observers might be enabled more easily to detect the comet, which was the more necessary as the object is extremely faint and small, and not capable of being seen except by means of the most perfect telescopes. By means of this ephemeris, Professor Challis, of Cambridge, found the comet on the night of the 28th of November, very nearly in the place assigned to it in the tables. Two observations only were then made upon it, which, however, were sufficient to enable M. Le Verrier to give still greater precision to his formulæ, by assigning a definite numerical value to a small quantity which before was left indeterminate. Lieutenant Stratford, with the formula thus corrected, calculated a more extensive and exact ephemeris, extending to the last day of March, and published it in January, 1851, in the Nautical Almanac.

The comet, though extremely faint and small, and consequently difficult of observation, continued to be observed by Professor Challis with the great Northumberland telescope at Cambridge, and by M. Struve at Pulkowa, and it was found to move in exact accordance with the predictions.

This comet again returned according to prediction in September 1858, when it was first observed at Berlin by M. Bruhns. It was extremely faint during the time of its appearance.

584. **De Vico's comet.**— On the 22nd of August, 1844, M. De

Vico, of the Roman Observatory, discovered a comet whose orbit was soon afterwards proved by M. Faye to be an ellipse of moderate excentricity, with a period of about 5½ years. It arrived at its perihelion on the 2nd of September, and continued to be observed until the 7th of December.

M. Le Verrier has made some computations, which render it somewhat probable that a comet which passed its perihelion in August, 1678, is identical with that discovered by M. De Vico.

585. **Brorsen's comet.**—On the 26th of February, 1846, M. Brorsen, of Kiel, discovered a faint comet, which was soon found to move in an elliptic orbit, with a period of about 5½ years. Its position in the heavens not being favourable, the observations upon it were few, and the resulting elements, consequently, not ascertained with all the precision that might be desired. Its re-appearance on its approach to the succeeding perihelion, was expected from September to November, 1851. It escaped observation, however, owing to its unfavourable position in relation to the sun. Its next perihelion passage took place in 1857, when it was re-discovered at Berlin by M. Bruhns on the 18th of March. Its period of revolution was found to be about 2026 days.

586. **Comets of D'Arrest and Winnecke.**—On the 27th of June, 1851, Dr. D'Arrest, of the Leipsic Observatory, discovered a faint comet, which M. Villarceau proved to move in an elliptic orbit, with a period of about 6½ years. The succeeding perihelion passage took place near the end of 1857, when it was discovered on the 5th of December at the Royal Observatory, Cape of Good Hope. A valuable series of observations extending to the 18th of January, 1858, were made at that observatory, under the direction of the present astronomer, Sir Thomas Maclear.

A comet discovered on the 8th of March, 1858, at Bonn, by Dr. Winnecke, is also supposed to be one of those whose orbit is of short period. A comparison of the elements with those of a comet observed in 1819, seemed to indicate that the two comets were really one object, whose orbit is elliptical with a period of about 5½ years. It would therefore have made seven revolutions in the interval since its first apparition, a result which agrees closely with that derived from theory. It can scarcely be doubted, therefore, that the two apparitions refer to the same object.

587. **Elliptic comet of 1743.**—A revision of the recorded observations of former comets by the more active and intelligent zeal of modern mathematicians and computers, has led to the discovery of the great probability of several among them having revolved in elliptic orbits, with periods not differing considerably from those of the comets above mentioned. The fact that these comets have not been re-observed on their successive returns

through perihelion, may be explained, either by the difficulty of observing them, owing to their unfavourable positions, and the circumstance of observers not expecting their re-appearance, their periodic character not being then suspected; or because they may have been thrown by the disturbing action of the larger planets into orbits such as to keep them continually out of the range of view of terrestrial observers.

Among those may be mentioned a comet which appeared in 1743, and was observed by Zanetti at Bologna; the observations indicate an elliptic orbit, with a period of about 5½ years.

588. **Elliptic comet of 1766.**— This comet, which was observed by Messier, at Paris, and by La Nux, at the Isle of Bourbon, revolved, according to the calculations of Burckhardt, in an ellipse with a period of 5 years.

589. **Lexell's comet.**— The history of astronomy has recorded one singular example of a comet which appeared in the system, made two revolutions round the sun in an elliptic orbit, and then disappeared, never having been seen either before or since.

This comet was discovered by Messier, in June 1770, in the constellation of Sagittarius, between the head and the northern extremity of the bow, and was observed during that month. It disappeared in July, being lost in the sun's rays. After passing through its perihelion, it re-appeared about the 4th of August, and continued to be observed until the first days of October, when it finally disappeared.

All the attempts of the astronomers of that day failed to deduce the path of this comet from the observations, until six years later, in 1776, Lexell showed that the observations were explained, not, as had been assumed previously, by a parabolic path, but by an ellipse, and one, moreover, without any example at that epoch, which indicated the short period of 5½ years.

It was immediately objected to such a solution, that its admission would involve the consequence that the comet, with a period so short, and a magnitude and splendour such as it exhibited in 1770, must have been frequently seen on former returns to perihelion; whereas no record of any such appearance was found.

To this Lexell replied, by showing that the elements of its orbit, derived from the observations made in 1770, were such that at its previous aphelion, in 1767, the comet must have passed within a distance of the planet Jupiter fifty-eight times less than its distance from the sun; and that consequently it must then have sustained an attraction from the great mass of that planet, more than three times more energetic than that of the sun; that consequently it was thrown out of the orbit in which it previously moved, into the elliptic orbit in which it actually moved in 1770;

that its orbit previously to 1767 was, according to all probability, a parabola; and, finally, that consequently moving in an elliptic orbit from 1767 to 1770, and having the periodicity consequent on such motion, it nevertheless moved only for the first time in its new orbit, and had never come within the sphere of the sun's attraction before this epoch.

Lexell further stated, that since the comet passed through its aphelion, which nearly intersected Jupiter's orbit at intervals of somewhat above 5½ years, and it encountered the planet near that point in 1767, the period of the planet being somewhat above 11 years, the planet after a single revolution, and the comet after two revolutions, must necessarily again encounter each other in 1779; and, that since the orbit was such that the comet must in 1779 pass at a distance from Jupiter 500 times less than its distance from the sun, it must suffer from that planet an action 250 times greater than the sun's attraction, and that therefore it would in all probability be again thrown into a parabolic or hyperbolic path; and if so, that it would depart for ever from our system to visit other spheres of attraction. Lexell, therefore, anticipated the final disappearance of the comet, which actually took place.

In the interval between 1770 and 1779, the comet would have returned once to perihelion; but its position was such that it must have been above the horizon only during the day, and therefore could not in the actual state of science be observed.

590. **Analysis of Laplace applied to Lexell's comet.**—At this epoch, analytical science had not yet supplied a definite solution of the problem of cometary disturbances. At a later period the question was resumed by Laplace, who in his celebrated work, the *Mécanique céleste*, gave the general solution of the following problem.

"The actual orbit of a comet being given, what was its orbit before, and what will be its orbit after being submitted to any given disturbing action of a planet near which it passes?"

591. **Its orbit before 1767 and after 1770 calculated by his formulæ.**—Applying this to the particular case of Lexell's comet, and assuming as data the observations recorded in 1770, Laplace showed that, before sustaining the disturbing action of Jupiter in 1767, the comet must have moved in an ellipse of which the semi-axis major was 13·293 and consequently that its period instead of being 5½ years, must have been 48½ years; and that the excentricity of the orbit was such, that its perihelion distance would be but little less than the mean distance of Jupiter, and that consequently it could never have been visible. It followed also that, after suffering the disturbing action of Jupiter, in 1779, the comet passed into an elliptic orbit whose semi-

axis major was 7·3, that its period was consequently 20 years, and that its excentricity was such, that its perihelion distance was more than twice the distance of Mars, and that in such an orbit it could not become visible.

592. **Revision of these researches by M. Le Verrier.**— This investigation has recently been revised by M. Le Verrier*, who has shown that the observations of 1770 were not sufficiently definite and accurate to justify conclusions so absolute. He has shown, that the orbit of 1770 is subject to an uncertainty comprised between certain definite limits; that tracing the consequences of this to the positions of the comet in 1767 and 1779, these positions are subject to still wider limits of uncertainty. Thus he shows that, compatibly with the observations of 1770, the comet might in 1779 pass either considerably outside, or considerably inside Jupiter's orbit, or might, as it was supposed to have done, have passed actually within the orbits of his satellites. He deduces finally the following general conclusions:—

1. That if the comet had passed within the orbits of the satellites, it must have fallen down upon the planet and coalesced with it; an incident which he thinks highly improbable, though not absolutely impossible.

2. The action of Jupiter may have thrown the comet into a parabolic or hyperbolic orbit, in which case it must have departed from our system altogether, never to return, except by the consequence of some disturbance produced in another sphere of attraction.

3. It may have been thrown into an elliptic orbit, having a great axis and long period, and so placed and formed that the comet could never become visible; a supposition within which comes the solution of Laplace.

4. It may have had merely its elliptic elements more or less modified by the action of the planet, without losing its character of short periodicity; a result which M. Le Verrier thinks the most probable, and which would render it possible that this comet may still be identified with some one of the many comets of short period, which the activity and sagacity of observers are continually discovering.

To facilitate such researches M. Le Verrier has given a table, including all the possible systems of elliptic elements of short period which the comet could have assumed, subject to the disturbing action of Jupiter in 1779, and taking the observations of 1770 within their possible limits of error.

He further demonstrates, that the orbit in which the comet moved antecedently to the disturbing action of Jupiter upon it in

* See *Mémoires de l'Académie des Sciences*, 1847, 1848.

1767, not only could not have been a parabola or hyperbola, but must have been an ellipse, whose major axis was considerably less than that which Laplace deduced from the insufficient observations of Messier. He shows that, before that epoch, the perihelion distance of the comet could not, under any possible supposition, have exceeded three times the earth's mean distance, and most probably was included between $1\frac{1}{2}$ and 2 times that distance; and that the semi-axis major of the orbit could not have exceeded $4\frac{1}{2}$ times the earth's mean distance, a magnitude 3 times less than that assigned to it by the calculations of Laplace.

593. **Process by which the identification of periodic comets may be decided.**—It must not, however, be supposed that it is sufficient to compare the actual elements of each periodic comet thus discovered, with the elements given in the table of M. Le Verrier, and to infer the absence of identity from their discordance. Such an inference would only be rendered valid by showing that in past ages, the comet in question had suffered no serious disturbing action by which the elements of its orbit could be considerably changed. To decide the question, a much more laborious and difficult process must be encountered; a process from which the untiring spirit of M. Le Verrier has not shrunk. It is necessary, in fine, to the satisfactory and conclusive solution of such a problem, that the periodic comet in question should be traced back through all its previous revolutions up to 1779, that all the disturbances which it suffered from the planets which it encountered in that interval be calculated and ascertained, and that by such means the orbit which it must have had previous to such disturbances, in 1779, be determined. Such orbit would then be compared with the table of possible orbits of Lexell's comet, as given by M. Le Verrier; and if it were found to be identical with any of them, the identity of the comet in question with that of Lexell, would be inferred with the highest degree of probability; but if, on the other hand, such discrepancies were found to prevail as must exceed all supposable errors of observation or calculation, the diversity of the comets would follow.

594. **Application of this process by M. Le Verrier to the comets of Faye, De Vico, and Brorsen, and that of Lexell.—Their diversity proved.**—M. Le Verrier has applied these principles to the comets of Faye, De Vico, and Brorsen; tracing back their histories during their unseen motions for three quarters of a century, and ascertaining the effects of the disturbing actions which they must severally have sustained from revolution to revolution, until he brought them to the epoch of 1779. On comparing the orbits thus determined with those of the table of possible orbits of Lexell's comet, he has shown that none of them can be identical

with it, however strongly some of the elements of their present orbits may raise such a presumption.

595. **Blainpain's comet of 1819.**—M. Blainpain discovered a comet at Marseilles on the 28th of November, 1819, which was observed at Milan until the 25th of January, 1820. The observations reduced and calculated by Professor Encke gave an elliptic orbit with a period a little short of 5 years. Clausen conjectures that this comet may be identical with that of 1743. It has not been seen since 1820.

596. **Pons' comet of 1819.**—A comet was discovered by M. Pons on the 12th of June, 1819, which was observed until the 19th of July. Professor Encke assigned to it an elliptic orbit, with a period of 5½ years.

597. **Pigott's comet of 1783.**—A comet, discovered by Mr. Pigott at New York in 1783, was shown by Burckhardt to have an elliptic orbit, with a period of 5⅓ years.

598. **Peters' comet of 1846.**—On the 26th of June, 1846, a comet was discovered at Naples by M. Peters, which was subsequently observed at Rome by De Vico, and continued to be seen until the 21st of July. An elliptic orbit is assigned to this comet, with a period of from 13 to 16 years; some uncertainty is attached, however, to this determination.

III. Elliptic Comets, whose mean distances are nearly equal to that of Uranus.

599. **Comets of long periods first recognised as periodic.**—It might be expected, that comets moving in elliptic orbits of small dimensions, and consequently having short periods, would have been the first in which the character of periodicity would be discovered. The comparative frequency of their returns to those positions near perihelion, where alone bodies of this class are visible from the earth, and the consequent possibility of verifying the fact of periodicity, by ascertaining the equality of the intervals between their successive returns to the same heliocentric position, to say nothing of the more distinctly elliptic form of the arcs of their orbits in which they can be immediately observed, would afford strong ground for such an expectation; nevertheless in this case, as has happened in so many others in the progress of physical knowledge, the actual results of observation and research have been directly contrary to such an anticipation; the most remarkable case of a comet of large orbit, long period, and rare returns, being the first, and those of small orbits, short periods, and frequent returns, the last whose periodicity has been discovered.

600. **Newton's conjectures as to the existence of comets**

of long periods. — It is evident that the idea of the possible existence of comets with periods shorter than those of the more remote planets, and orbits circumscribed within the limits of the solar system, never occurred to the mind either of Newton or any of his contemporaries or immediate successors.

In the third book of his PRINCIPIA, he calls comets a species of planets, revolving in elliptic orbits of a very oval form. But he continues, "I leave to be determined by others the transverse diameters and periods, by comparing comets which return *after long intervals of time* to the same orbits."

It is interesting to observe the avidity with which minds of a certain order snatch at such generalisations, even when but slenderly founded upon facts. These conjectures of Newton were soon after adopted by Voltaire: "Il y a quelque apparence," says he, in an essay on comets, "qu'on connaîtra un jour un certain nombre de ces autres planètes qui, sous le nom de comètes, tournent comme nous autour du soleil, mais il ne faut pas espérer qu'on les connaissent toutes."

And again, elsewhere, on the same subject: —

> "Comètes, que l'on craint à l'égal du tonnerre,
> Cessez d'épouvanter les peuples de la terre;
> Dans une ellipse immense achevez votre cours,
> Remontez, descendez près de l'astre des jours."

601. **Halley's researches.** — Extraordinary as these conjectures must have appeared at the time, they were soon strictly realised. Halley undertook the labour of examining the circumstances attending all the comets previously recorded, with a view to discover whether any, and which of them, appeared to follow the same path. He found that a comet which had been observed by himself, by Newton, and their contemporaries in 1682, followed a path while visible, which coincided so nearly with those of comets which had been observed in 1607, and in 1531, as to render it extremely probable, that these objects were the same identical comet, revolving in an elliptic orbit of such dimensions, as to cause its return to perihelion at intervals of 75—76 years.

The comet of 1682 had been well observed by La Hire, Picard, Hevelius, and Flamsteed, whose observations supplied all the data necessary to calculate its path while visible. That of 1607 had been observed by Kepler and Longomontanus; and that of 1531, by Pierre Apian at Ingolstadt, the observations in both cases being also sufficient for the determination of the path of the body, with all the accuracy necessary for its identification.

602. **Halley predicts its re-appearance in 1758-9.** — Of the identity of the paths while visible on each of these appearances

Halley entertained no doubt; and announced to the world the discovery of the elliptic motion of comets, as the result of combined observation and calculation, and entitled to as much confidence as any other consequence of an established physical law; and predicted the re-appearance of this body, on its succeeding return to perihelion, in 1758-9. He observed, however, that as in the interval between 1607 and 1682, the comet passed near Jupiter, its velocity must have been augmented, and consequently its period shortened by the action of that planet. This period, therefore, having been only seventy-five years, he inferred that the following period would probably be seventy-six years or upwards; and consequently that the comet ought not to be expected to appear until the end of 1758, or the beginning of 1759. It is impossible to imagine any quality of mind more enviable than that which, in the existing state of mathematical physics, could have led to such a prediction. The imperfect state of science rendered it impossible for Halley to offer to the world a demonstration of the event which he foretold. "He therefore," says M. de Pontécoulant, "could only announce these felicitous conceptions of a sagacious mind as mere intuitive perceptions, which must be received as uncertain by the world, however he might have felt them himself, until they could be verified by the process of a rigorous analysis."

Subsequent researches gave increased force to Halley's prediction; for it appeared from the ancient records of observers, that comets had been seen in 1456* and 1378, whose elements were identical with those of the comet of 1682.

* The appearance of this comet in 1456, was described by contemporary authorities to have been an object of "unheard-of magnitude;" it was accompanied by a tail of extraordinary length, which extended over sixty degrees, (a third of the heavens,) and continued to be seen during the whole of the month of June. The influence which was attributed to this appearance, renders it probable that in the record there exists more or less of exaggeration. It was considered as the celestial indication of the rapid success of Mahommed II., who had taken Constantinople, and struck terror into the whole Christian world. Pope Calixtus II. levelled the thunders of the Church against the enemies of his faith, terrestrial and celestial, and in the same bull exorcised the Turks and the comet; and in order that the memory of this manifestation of his power should be for ever preserved, he ordained that the bells of all the churches should be rung at midday, — a custom which is preserved in those countries to our times. It must be admitted that, notwithstanding the terrors of the Church, the comet pursued its course with as much ease and security as those with which Mahommed converted the church of St. Sophia into his principal mosque.

The extraordinary length and brilliancy which was ascribed to the tail upon this occasion, have led astronomers to investigate the circumstances under which its brightness and magnitude would be the greatest possible; and, upon tracing back the motion of the comet to the year 1456, it has

603. **Great advance of mathematical and physical sciences between 1682 and 1759.**—In the interval of three quarters of a century which elapsed between the announcement of Halley's prediction and the date of its expected fulfilment, great advances were made in mathematical science; new and improved methods of investigation and calculation were invented; and, in fine, the theory of gravitation was pursued with extraordinary activity and success through its consequences in the mutual disturbances produced upon the motions of the planets and satellites, by the attraction of their masses one upon another. As the epoch of the expected return of the comet to its perihelion approached, therefore, the scientific world resolved to divest, as far as possible, the prediction, of that vagueness which necessarily attended it owing to the imperfect state of science at the time it was made, and to calculate the exact effects of those planets whose masses were sufficiently great, in accelerating or retarding its motion while passing near them.

604. **Exact path of the comet on its return, and time of its perihelion calculated and predicted by Clairaut and Lalande.**—This inquiry, which presented great mathematical difficulties and involved enormous arithmetical labour, was undertaken by Clairaut and Lalande: the former, a mathematician and natural philosopher, who had already applied with great success the principles of gravitation to the motions of the moon, undertook the purely analytical part of the investigation, which consisted in establishing certain general algebraical formulæ, by which the disturbing actions exerted by the planets on the comet were expressed; and Lalande, an eminent practical astronomer, undertook the labour of the arithmetical computations, in which he was assisted by a lady, Madame Lepaute, whose name has thus become celebrated in the annals of science.

These elaborate calculations being completed, Clairaut presented the result of their joint labours, in a memoir to the Academy of Sciences of Paris*, in which he predicted the next arrival of

been found that it was then actually under the circumstances of position with respect to the earth and sun most favourable to magnitude and splendour. So far, therefore, the results of astronomical calculation corroborate the records of history.

* When it is considered that the period of Halley's comet is about seventy-five years, and that every portion of its course, for two successive periods, was necessary to be calculated separately in this way, some notion may be formed of the labour encountered by Lalande and Madame Lepaute. "During six months," says Lalande, "we calculated from morning till night, sometimes even at meals; the consequence of which was, that I contracted an illness which changed my constitution for the remainder of my life. The assistance rendered by Madame Lepaute was such, that without her we never could have dared to undertake this enormous labour, in which it was

the comet at perihelion, on the 18th of April, 1759; a date, however, which, before the re-appearance of the comet, he found reason to change to the 11th of April; and assigned the path which the comet would follow while visible, as determined by the following data:—

Inclination.	Long. of node.	Long. of perihel.	Perihel. dist.	Direction.
17° 37′	53° 50′	303° 10′	0·58	retrograde.

605. **Remarkable anticipation of the discovery of Uranus.** — In announcing his prediction, Clairaut stated, that the time assigned for the approaching perihelion might vary from the actual time to the extent of a month; for that independently of any error either in the methods or process of calculation, the event might deviate more or less from its predicted occurrence, by reason of the attraction of *an undiscovered planet of our system revolving beyond the orbit of Saturn.* In twenty-two years after this time, this conjecture was realised by the discovery of the planet Uranus, by the late Sir William Herschel, revolving round the sun nearly one thousand millions of miles beyond the orbit of Saturn!

606. **Prediction of Halley and Clairaut fulfilled by re-appearance of the comet in 1758-9.** — The comet, in fine, appeared in December, 1758, and followed the path predicted by Clairaut, which differed but little from that which it had pursued on former appearances, as will be seen by a comparison of the elements as given above with those since ascertained. It passed through perihelion on the 13th of March, within 22 days of the time, and within the limit of the possible errors assigned by Clairaut.

607. **Disturbing action of a planet on a comet explained.** — The general effects of a planet in accelerating or retarding the motion of a comet are easily explained, although the exact details of the disturbances are too complicated to admit of any exposition here.

necessary to calculate the distance of each of the two planets, Jupiter and Saturn, from the comet, and their attraction upon that body, separately, for every successive degree, and for 150 years."

The name of Madame Lepaute does not appear in Clairaut's memoir; a suppression which Lalande attributes to the influence exercised by another lady to whom Clairaut was attached. Lalande, however, quotes letters of Clairaut, in which he speaks in terms of high admiration of "la savante calculatrice." The labours of this lady in the work of calculation (for she also assisted Lalande in constructing his *Ephemerides*) at length so weakened her sight that she was compelled to desist. She died in 1788, while attending on her husband, who had become insane. See the articles on comets, by Prof. de Morgan, in the *Companion to the British Almanac* for the year 1833

Let P, *fig.* 94, represent the place of the disturbing planet, and C that of the comet. The attraction of the planet on the comet will then be a force directed from C towards P, and by the principle of the composition of forces, is equivalent to two components, one C *m* in the direction of the comet's path, and the other C *n* perpendicular to that path. If the motion of the comet be directed from C towards *m*, it will be accelerated; and if it be directed from C towards *m'*, it will be retarded by that component of the planet's attraction which is directed from C to *m*. The other component C *n* being at right angles to the comet's motion, will have no direct effect either in accelerating or retarding it.

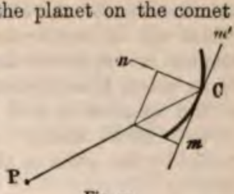


Fig. 94.

It appears, therefore, in general that, if the direction of the comet's motion C*m* make an acute angle with the line C P drawn to the planet, the planet's attraction will accelerate it; and if its direction C *m'* make an obtuse angle with the line C P, it will retard it.

This being understood, the disturbing action of a planet such as Jupiter or Saturn on a comet such as Halley's may be easily comprehended. In *fig.* 95, the orbit of the comet is represented at A *c* P *c''* in its proper proportions, A P being the major axis, P the place of perihelion, A that of aphelion, and S that of the focus in which the sun is placed. The small circle described round S represents in its proper proportions the orbit of the earth, whose distance is about twice that of the comet when the latter is at perihelion. The circle *p p' p''* represents in its proper proportions the orbit of Jupiter, which, for illustration, we shall consider as the disturbing planet.

Fig. 95.

It will be apparent on the mere inspection of the diagram, that lines drawn from the planet, whatever be its place, to any point whatever of the comet's path between its aphelion A and the point *m'* where it arrives at the orbit

of the planet in approaching the sun, will make acute angles with the direction of the comet's motion; and that, consequently the comet will be accelerated by the action of the planet. In like manner, it is apparent that lines drawn from the planet, whatever be its place, to any point whatever of the comet's path between *m* and aphelion A, will make obtuse angles with the direction of the comet's motion; and, consequently, the comet will be retarded by the action of the planet, in departing from the sun, from *m* to A.

In that part of the comet's path which lies within the planet's orbit, the action of the planet alternately accelerates and retards it, according to their relative position. If the planet be at *p*, suppose *p o* drawn so as to be at right angles to the path of the comet. Between *m'* and *o* the action of the planet at *p* will accelerate the comet, and after the comet passes *o* it will retard it. In like manner if the planet be at *p''*, it will first retard the motion of the comet proceeding from *m'* towards A, and will continue to do so until the line of direction becomes perpendicular to that of the comet's motion, after which it will accelerate it.

It appears, therefore, that during the period of the comet the disturbing action of the planet is subject to several changes of direction, owing partly to the change of position of the comet and partly to that of the planet; and the total effect of the disturbing action of the planet on the comet's period is found by taking the difference between the total amount of all the accelerating and all the retarding actions.

In the case of the planet Jupiter and Halley's comet, the former makes nearly seven complete revolutions in a single period of the comet; and consequently its disturbing action is not only subject to several changes of direction, but also to continual variation of intensity, owing to its change of distance from the comet.

Small as the arc *m'* P *m* of the comet's path is which is included within the orbit of Jupiter, the fraction of the period in which this arc is traversed by the comet is much smaller, as will be apparent by considering the application of the principle of equable areas to this case. The time taken by the comet to move over the arc *m'* P *m* is in the same proportion to its entire period, as the area included between the arc *m'* P *m* and the lines *m'* S and *m* S is to the entire area of the ellipse A P.

To simplify the explanation, the orbit of the comet has here been supposed to be in the plane of that of the disturbing planet. If it be not, the disturbing action will have another component at right angles to the plane of the comet's orbit, the effect of which will be a tendency to vary the inclination.

608. **Effect of the perturbing action of Jupiter and Saturn on Halley's comet between 1682 and 1758.** — The result of the investigation by Clairaut showed that the total effect of the disturbing action of Jupiter and Saturn on Halley's comet between its perihelions in 1682 and in 1759, was to increase its period by 618 days as compared with the time of its preceding revolution, of which increase, 100 days were due to the action of Saturn, and 518 to that of Jupiter.

Clairaut did not take into account the disturbing action of the earth, which was not altogether inconsiderable, and could not allow for those of the undiscovered planets Uranus and Neptune. The effects of the action of the other planets, Mars, Venus, Mercury, and the planetoids, are in these cases insignificant.

609. **Calculations of its return in 1835–6.** — In the interval of three-quarters of a century which preceded the next re-appearance of this comet, science continued to progress, and instruments of observation and principles and methods of investigation were still further improved; and, above all, the number of observers was greatly augmented. Before the epoch of its return in 1835, its motions, and the effects produced upon them by the disturbing action of the several planets, were computed by MM. Damoiseau, Pontécoulant, Rosenberger, and Lehmann, who severally predicted its arrival at perihelion: —

Damoiseau - - - -	4th Nov. 1835
Pontécoulant - - - -	7th „
Rosenberger - - - -	11th „
Lehmann - - - -	26th „

610. **Predictions fulfilled.** — These predictions were all published before July, 1835. The comet was seen at Rome on the 5th of August, in a position within *one degree* of the place assigned to it for that day in the ephemeris of M. Rosenberger. On the 20th of August it became visible to all observers, and pursued the course with very little deviation which had been assigned to it in the ephemerides, arriving at its perihelion on the 16th of November, being very nearly a mean between the four epochs assigned in the predictions.

After this, passing south of the equator, it was not visible in northern latitudes, but continued to be seen in the southern hemisphere until the 5th of May, 1836, when it finally disappeared, not again to return until the year 1911.

It appears that the mean distance of this comet is about eighteen times that of the earth, and that it is consequently a little less than the mean distance of Uranus. When in perihelion, its distance from the sun is about half the earth's distance, while its distance in aphelion is above thirty-five times the earth's distance, and therefore seventy times its perihelion distance.

611. **Pons' comet of 1812.**—On the 20th of July, 1812, a comet was discovered by M. Pons, whose orbit was calculated by Professor Encke, and was found to be an ellipse of such dimensions as to give a period of 75½ years, equal to that of Halley's comet.

612. **Olbers' comet of 1815.**—On the 6th of March, 1815, Dr. Olbers discovered at Bremen a comet whose orbit, calculated by Professor Bessel, proved to be an ellipse, with a period of 74 years. The next perihelion passage of this comet is predicted for the 9th of February, 1887.

613. **De Vico's comet of 1846.**—On the 28th of February, 1846, M. de Vico discovered a comet at Rome, whose orbit appears to be an ellipse, with a period of 72–73 years.

614. **Brorsen's comet of 1847.**—A comet was discovered by M. Brorsen at Altona, on the 20th of July, 1847; the orbit of which appears to be an ellipse, with a period of about 75 years.

615. **Westphal's comet of 1852.**—A comet was discovered at Göttingen, by M. Westphal, on the 27th of June, 1852. Its orbit also appears to be an ellipse, with a period of about 70 years.

616. **Comets with orbits of great excentricity, &c.**—With regard to comets having elliptic orbits of great excentricity, as well as those whose orbits are parabolic or hyperbolic, it is unnecessary to enter into any detail. Even comets whose orbits have been found to be elliptical, have periods amounting in several cases to many thousands of years, whereas those whose orbits are parabolic or hyperbolic have appeared amongst us for a short time, then leaving our skies never, most probably, to return. Some of these comets have, however, in their time created considerable interest by their magnitude and brilliancy. As an example, all can recollect the magnificent appearance in the heavens of Donati's comet in the autumn of 1858, yet a period of upwards of two thousand years must elapse before it can again be visible to the inhabitants of the earth. Astronomically speaking, these splendid comets which cause such universal interest at the time of their visibility, sink into insignificance, on account of their uncertain period, in comparison with the faint comets of short period, such as Encke's, Biela's, Faye's, and others, the orbits of which are known with nearly the same accuracy as those of the separate planets of the solar system.

We have not space to give a catalogue of all the comets which may be classed under this section, but if the reader be desirous of entering more fully into the knowledge of the existence and motions of these wandering bodies, reference can be made to the work on comets by Mr. Hind, who has devoted so much attention to the subject of cometary astronomy. Mr. Hind has given a catalogue of the orbits of all the comets hitherto computed, together with explanatory notes giving considerable information.

IV. Physical Constitution of Comets.

617. **Apparent form — Head and Tail.** — Comets in general, and more especially those which are visible without a telescope, present the appearance of a roundish mass of illuminated vapour or nebulous matter, to which is often, though not always, attached a train more or less extensive, composed of matter having a like appearance. The former is called the HEAD, and the latter the TAIL of the comet.

618. **Nucleus.** — The illumination of the head is not generally uniform. Sometimes a bright central spot is seen in the nebulous matter which forms it. This is called the NUCLEUS.

The nucleus sometimes appears as a bright stellar point, and sometimes presents the appearance of a planetary disk seen through a nebulous haze. In general, however, on examining the object with high optical power, these appearances are changed, and the object seems to be a mere mass of illuminated vapour from its borders to its centre.

619. **Coma.** — When a nucleus is apparent, or supposed to be so, the nebulous haze which surrounds it and forms the exterior part of the head is called the *coma*.

620. **Origin of the name.** — These designations are taken from the Greek word κομή (komé), hair, the nebulous matter composing the coma and tail being supposed to resemble hair, and the object being therefore called κομήτης (kometes), a hairy star.

621. **Magnitude of the head.** — As the brightness of the coma gradually fades away towards the edges, it is impossible to determine with any great degree of precision its real dimensions. These, however, are obviously subject to enormous variation, not only in different comets compared one with another, but even in the same comet during the interval of a single perihelion passage. The greatest of those which have been submitted to micrometrical measurement was the great comet of 1811, the diameter of the head of which was found to be not less than 1½ millions of miles, which would give a volume greater than that of the sun in the ratio of about 2 to 1. The diameter of the head of Halley's comet when departing from the sun, in 1836, at one time measured 357,000 miles, giving a volume more than sixty times that of Jupiter. These are, however, the greatest dimensions which have been observed in this class of objects, the diameter rarely exceeding 200,000 miles, and being generally less than 100,000.

622. **Magnitude of the nucleus.** — Attempts have been made, where nuclei were perceivable, to estimate their magnitude, and

diameters have been assigned to them, varying from 100 to 5000 miles. For the reasons, however, already explained, these results must be regarded as very doubtful.

Those who deny the existence of solid matter within the coma, maintain that even the most brilliant and conspicuous of those bodies, and those which have presented the strongest resemblance to planets, are more or less transparent. It might be supposed that a fact so simple as this, in this age of astronomical activity, could not remain doubtful; but it must be considered that the combination of circumstances which alone would test such a question, is of rare occurrence. It would be necessary that the centre of the head of the comet, although very small, should pass critically over a star, in order to ascertain whether such star is visible through it. With comets having extensive comæ without nuclei, this has sometimes occurred; but we have not had such satisfactory examples in the more rare instances of those which have distinct nuclei.

In the absence of a more decisive test of the occultation of a star by the nucleus, it has been maintained that the existence of a solid nucleus may be fairly inferred from the great splendour which has attended the appearance of some comets. A mere mass of vapour could not, it is contended, reflect such brilliant light. The following are the examples adduced by Arago:—

In the year 43 before Christ, a comet appeared which was said to be visible to the naked eye by daylight. It was the comet which the Romans considered to be the soul of Cæsar transferred to the heavens after his assassination.

In the year 1402 two remarkable comets were recorded. The first was so brilliant that the light of the sun at noon, at the end of March, did not prevent its nucleus, or even its tail, from being seen. The second appeared in the month of June, and was visible also for a considerable time before sunset.

In the year 1532 the people of Milan were alarmed by the appearance of a star which was visible in the broad daylight. At that time Venus was not in a position to be visible, and consequently it is inferred that this star must have been a comet.

The comet of 1577 was discovered on the 13th of November by Tycho Brahe, from his observatory on the isle of Huene, in the Sound, before sunset.

On the 1st of February, 1744, Chizeaux observed a comet more brilliant than the brightest star in the heavens, which soon became equal in splendour to Jupiter, and in the beginning of March it was visible in the presence of the sun. By selecting a proper position for observation, on the 1st of March it was seen at one o'clock in the afternoon without a telescope.

Such is the amount of evidence which observation has supplied respecting the existence of a solid nucleus. The most that can be said of it is, that it presents a plausible argument, giving some

probability, but no positive certainty, that comets have visited our system which have solid nuclei; but, meanwhile, this can only be maintained with respect to few: most of those which have been seen, and all to which very accurate observations have been directed, have afforded evidence of being mere masses of semi-transparent matter.

623. **The tail.**—Although by far the greater majority of comets are not attended by tails, yet that appendage, in the popular mind, is more inseparable from the idea of a comet than any other attribute of these bodies. This proceeds from its singular and striking appearance, and from the fact that most comets visible to the naked eye have had tails. In the year 1531, on the occasion of one of the visits of Halley's comet to the solar system, Pierre Apian observed that the comet generally presented its tail in the direction opposite to that of the sun. This principle was hastily generalised, and is even at present too generally adopted. It is true that in most cases the tail extends itself from that part of the comet which is most remote from the sun; but its direction rarely corresponds with the direction which the shadow of the comet would take. Sometimes it has happened that the tail forms with a line drawn to the sun a considerable angle, and cases have occurred when it was actually at right angles to it.

Another character which has been observed to attach to the tails of comets, which, however, is not invariable, is, that they incline constantly toward the region last quitted by the comet, as if in its progress through space it were subject to the action of some resisting medium, so that the nebulous matter with which it is invested, suffering more resistance than the solid nucleus, remains behind it and forms the tail.

The tail sometimes appears to have a curved form. That of the comet of 1744 formed almost a quadrant. It is supposed that the convexity of the curve, if it exists, is turned in the direction from which the comet moves. It is proper to state, however, that these circumstances regarding the tail have not been clearly and satisfactorily ascertained.

The tails of comets are not of uniform breadth or diameter; they appear to diverge from the comet, enlarging in breadth and diminishing in brightness as their distance from the comet increases. The middle of the tail usually presents a dark stripe, which divides it longitudinally into two distinct parts. It was long supposed that this dark stripe was the shadow of the body of the comet, and this explanation might be accepted if the tail was always turned from the sun; but we find the dark stripe equally exists when the tail, being turned sideward, is exposed to the effect of the sun's light.

This appearance is usually explained by the supposition that the tail is a hollow, conical shell of vapour, the external surface of which possesses a certain thickness. When we view it, we look through a considerable thickness of vapour at the edges, and through a comparatively small quantity at the middle. Thus, upon the supposition of a hollow cone, the greatest brightness would appear at the sides, and the existence of a dark space in the middle would be perfectly accounted for.

The tails of comets are not always single; some have appeared at different times with several separate tails. The comet of 1744, which appeared on the 7th or 8th of March, had six tails, each about 4° in breadth, and of considerable length. Their sides were well defined and tolerably bright, and the spaces between them were as dark as the other parts of the heavens.

The tails of comets have frequently appeared, not only of immense real length, but extending over considerable spaces of the heavens. It will be easily understood that the apparent length depends conjointly upon the real length of the tail, and the position in which it is presented to the eye. If the line of vision be at right angles to it, its length will appear as great as it can do at its existing distance; if it be oblique to the eye, it will be foreshortened, more or less, according to the angle of obliquity. The real length of the tail is easily calculated when the apparent length is observed and the angle of obliquity known.

In respect of magnitude, the tails are unquestionably the most stupendous objects which the discoveries of the astronomer have ever presented to human contemplation.

The following are the results of the observation and measurement of a few of the more remarkable:—

Date of Appearance.	Greatest observed Length of Tail.
	miles.
1847	5,000,000
1744	19,000,000
1769	40,000,000
1858	45,000,000
1618	50,000,000
1680	100,000,000
1811	100,000,000
1811	130,000,000
1843	200,000,000

The magnitude of these prodigious appendages is even less amazing than the brief period in which they sometimes emanate from the head. The tail of the comet of 1843, long enough to stretch from the sun to the planetoids, was formed in less than twenty days.

624. **Mass, volume, and density of comets.**—The masses of comets, like those of the planets, would be ascertained if the reciprocal effects of their gravitation, and those of any known bodies in the system, could be observed. But although the disturbing action of the planets on these bodies is conspicuous, and its effects have been calculated and observed, not the slightest effect of the same kind has ever been ascertained to be produced by them, even upon the smallest bodies in the system, and those to which comets have approached most nearly.

Notwithstanding the enormous number of comets, observed and unobserved, which constantly traverse the solar system in all conceivable directions; notwithstanding the permanent revolution of the periodic comets, whose presence and orbits have been ascertained; notwithstanding the frequent visits of comets, which so thoroughly penetrate the system as almost to touch the surface of the sun at their perihelion, the motions of the various bodies of the system, great and small, planets major and minor, planetoids and satellites, go on precisely as if no such bodies as the comets approached their neighbourhood. Not the smallest effects of the attraction of such visitors are discoverable.

Now since, on the other hand, the disturbing effects of the planets upon the comets are strikingly manifest, and since the comets move in elliptic, parabolic, or hyperbolic orbits, of which the sun is the common focus, it is demonstrated that these bodies are composed of ponderable matter, which is subject to all the consequences of the law of gravitation. It cannot, therefore, be doubted that the comets do produce a disturbing action on the planets, although its effects are inappreciable even by the most exact observation. Since, then, the disturbances mutually produced are in the proportion of the disturbing masses, it follows that the masses of the comets must be smaller beyond all calculation than the masses even of the smallest bodies among the planets primary or secondary.

The volumes of comets in general exceed those of the planets in a proportion nearly as great as that by which the masses of the planets exceed those of the comets. The consequence obviously resulting from this is, that the density of comets is incalculably small.

Their densities in general are probably thousands of times less than that of the atmosphere in the stratum next the surface of the Earth.

625. **Light of comets.**—That planets are not self-luminous, but receive their light from the sun, is proved by their phases, and by the shadows of their satellites, which are projected upon them when the latter are interposed between them and the sun.

These tests are inapplicable to comets. They exhibit no phases, and are attended by no bodies to intercept the sun's light. But, unless it could be shown that a comet is a solid mass, impenetrable to the solar rays, the non-existence of phases is not a proof that the body does not receive its light from the sun.

A mere mass of cloud or vapour, though not self-luminous, but rendered visible by borrowed light, would still exhibit no effect of this kind: its imperfect opacity would allow the solar light to affect its constituent parts throughout its entire depth — so that, like a thin fleecy cloud, it would appear not superficially illuminated, but receiving and reflecting light through all its dimensions. With respect to comets, therefore, the doubt which has existed is, whether the light which proceeds from them, and by which they become visible, is a light of their own, or is the light of the sun shining upon them, and reflected to our eyes like light from a cloud. Among several tests which have been proposed to decide this question, one suggested by Arago merits attention.

It has been already shown (O. 364 *et seq.*) that the apparent brightness of a visible object is the same at all distances, supposing its real brightness to remain unchanged. Now if comets shone with their proper light, and not by light received from the sun, their apparent brightness would not decrease as they would recede from the sun, and they would cease to be visible, not because of the faintness of their light, but because of the smallness of their apparent magnitude. Now the contrary is found to be the case. As the comet retires from the sun its apparent brightness rapidly decreases, and it ceases to be visible from the mere faintness of its light, while it still subtends a considerable visual angle.

626. **Enlargement of magnitude on departing from the sun.** — It will doubtless excite surprise, that the dimensions of a comet should be enlarged as it recedes from the source of heat. It has been often observed in astronomical inquiries, that the effects, which at first view seem most improbable, are nevertheless those which frequently prove to be true; and so it is in this case. It was long believed that comets enlarged as they approached the sun; and this supposed effect was naturally and probably ascribed to the heat of the sun expanding their dimensions. But more recent and exact observations have shown the very reverse to be the fact. Comets increase their apparent volume as they recede from the sun; and this is a law to which there appears to be no well-ascertained exception. This singular and unexpected phenomenon has been attempted to be accounted for in several ways. Valz ascribed it to the pressure of the solar atmosphere acting upon the comet; that atmosphere being more dense near the sun, com-

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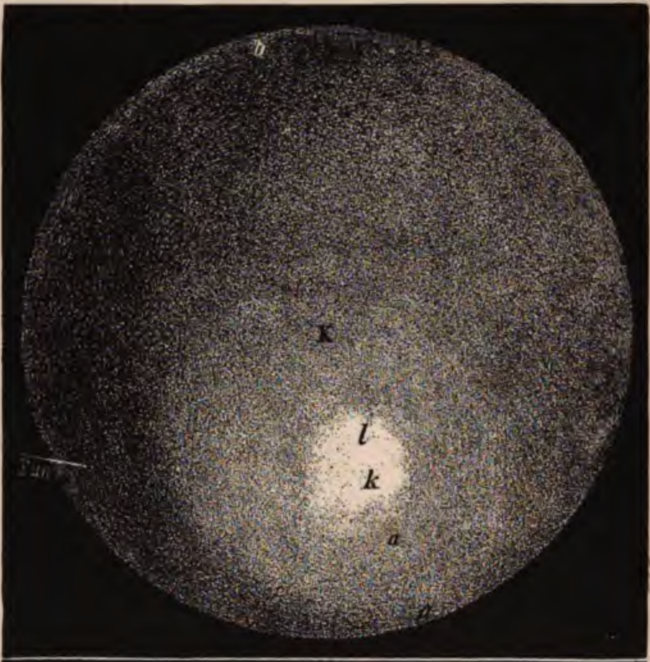

2

ENCKÉ'S COMET, 1828.

Approaching the sun. From telescopic drawings by Struve.

1. Nov. 7. 2. Nov. 30.

presses the comet and diminishes its dimensions; and, at a greater distance, being relieved from this coercion, the body swells to its natural bulk. A very ingenious train of reasoning was produced in support of this theory. The density of the solar atmosphere and the elasticity of the comet, being assumed to be such as they might naturally be supposed, the variations of the comet's bulk are deduced by strict reasoning, and show a surprising coincidence with the observed change in the dimensions. But this hypothesis is tainted by a fatal error. It proceeds upon the supposition that the comet, on the one hand, is formed of an elastic gas or vapour; and, on the other, that it is impervious to the solar atmosphere through which it moves. To establish the theory, it would be necessary to suppose that the elastic fluid composing the comet should be surrounded by a *nappe* or envelope as elastic as the fluid composing the comet, and yet wholly impenetrable by the solar atmosphere.

After several ingenious hypotheses * having been proposed and successively rejected for explaining this phenomenon, it seems now agreed to ascribe it to the action of the varying temperature to which the vapour which composes the nebulous envelope is exposed. As the comet approaches the sun, this vapour is converted by intense heat into a pure, transparent, and therefore invisible elastic fluid. As it recedes from the sun, the temperature decreasing, it is partially and gradually condensed, and assumes the form of a semi-transparent visible cloud, as steam does escaping from the valve of a steam boiler. It becomes more and more voluminous as the distance from the source of heat, and therefore the extent of condensation, is augmented.

627. **Professor Struve's drawings of Encke's comet.**— Professor Struve made a series of observations on the comet of Encke, at the period of its reappearance in 1828, and by the aid of the great Dorpat telescope, made the drawings given in Plate XXIII. *figs.* 1 and 2.

Fig. 1, represents the comet as it appeared on the 7th of November, the diameters a b and c d measuring each 18′. The brightest part of the comet extended from a to κ, and was consequently excentric to it, the distance of the centre of brightness from the centre of magnitude being κ K. Between the 7th and the 30th of November, the magnitude of the comet decreased from that represented in *fig.* 1, to that represented in *fig.* 2; but the apparent brightness was so much increased, that at the latter date it was visible to the naked eye as a star of the 6th magnitude. The apparent diameter was then reduced to 9′.

* For several of these, see Sir J. Herschel's memoir in the *Memoirs of the Royal Astronomical Society*, vol. vi. p. 104.

On the 7th of November a star of the 11th magnitude was see through the comet, so near the centre of brightness that it was fo a moment mistaken for a nucleus. The brightness of the star wa not in the least perceptible degree dimmed by the mass of cometar matter through which its light passed.

It was evident that the increase of the brightness of the come on the 30th of November must be ascribed to the contraction, an consequent condensation, of the nebulous matter composing it i receding from the sun, for its distance from the earth on the 7th o November, when the nebulous matter subtended an angle of 18′ was 0·515 (the earth's mean distance from the sun being = 1) while its distance on the 30th, when it subtended an angle of 9′ was only 0·477. Its cubical dimensions must, therefore, have been diminished, and the density of the matter composing it augmented, in more than an eight-fold proportion.

628. **Remarkable physical phenomena manifested by Halley's comet.**—The expectation so generally entertained, that on the occasion of its return to perihelion in 1835, this come would afford observers occasion for obtaining new data, for the foundation of some satisfactory views respecting the physical constitution of the class of which it is so striking an example, was no disappointed. It no sooner reappeared than phenomena began to be manifested, preceding and accompanying the gradual formation of the tail, the observation of which has been most justly regarded as forming a memorable epoch in astronomical history.

Happily, these strange and important appearances were observed with the greatest zeal, and delineated with the most elaborate and scrupulous fidelity, by several eminent astronomers in both hemispheres. MM. Bessel at Königsberg, Schwabe at Dessau, and Struve at Pulkowa, and Sir J. Herschel and Mr. Maclear * at the Cape of Good Hope, have severally published their observations, accompanied by numerous drawings, exhibiting the successive transformations presented under the physical influence of varying temperature, in its approach to and departure from the sun.

The comet first became visible as a small round nebula, without a tail, and having a bright point more intensely luminous than the rest excentrically placed within it. On the 2d of October the tail began to be formed, and, increasing rapidly, acquired a length of about 5° on the 5th; on the 20th it attained its greatest length, which was 20°. It began after that day to decrease, and its diminution was so rapid, that on the 29th it was reduced to 3°, and on the 5th of November to 2½°. The comet was observed on the

* Now Sir Thomas Maclear.

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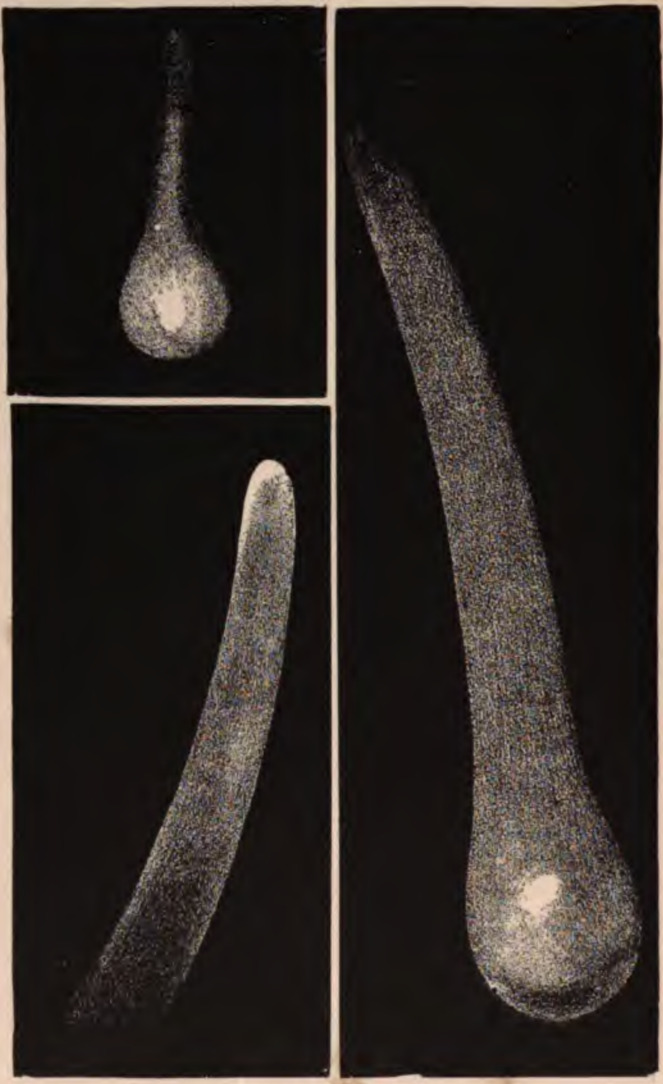
XXIV.



1 2 3

HALLEY'S COMET, 1835.

Approaching the sun. From drawings by M. Struve.

1. Sept. 29. 2. Oct. 5. 3. Oct. 29.

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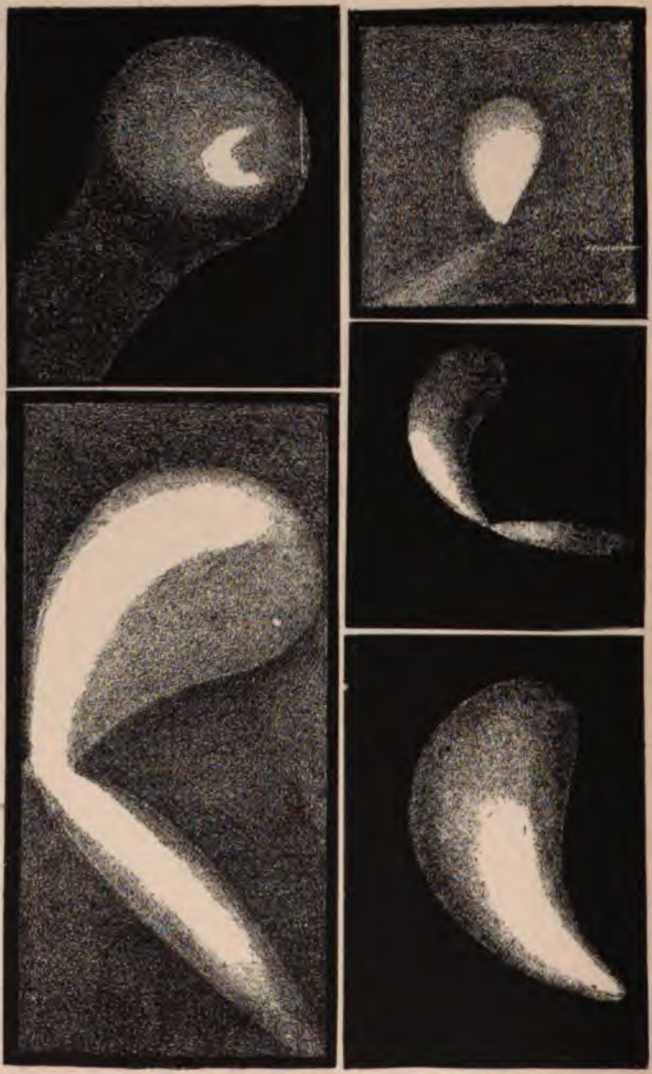
XXV.

1 3 4 2 5



HALLEY'S COMET, 1835.

Approaching the sun. From drawings by M. Struve.

1. Oct. 8. 2. Oct. 9. 3. Oct. 10. 4. Oct. 12. 5. Oct. 14.

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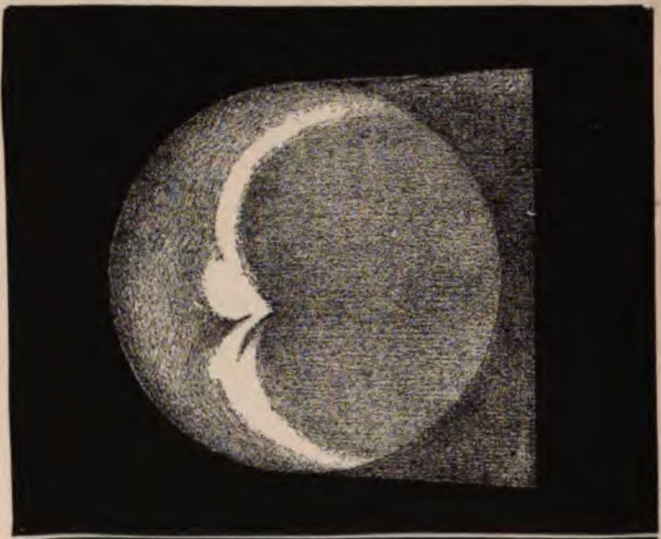
1



2

HALLEY'S COMET, 1835.

Approaching the sun. From drawings by Struve.

1. Oct. 29. 2. Nov. 5.

day of its perihelion by M. Struve, at the Observatory of Pulkowa, when no tail whatever was apparent.

The circumstances which accompanied the increase of the tail, from the 2nd of October, until its disappearance, were extremely remarkable, and were observed with scrupulous precision, simultaneously by Bessel at Königsberg, by Struve at Pulkowa, and by Schwabe at Dessau, all of whom made drawings from time to time, delineating the successive changes which it underwent.

On the 2nd, the commencement of the formation of the tail took place by the appearance of a violent ejection of nebulous matter from that part of the comet which was presented towards the sun. This ejection was, however, neither uniform nor continuous. Like the fiery matter issuing from the crater of a volcano, it was thrown out at intervals. After the ejection, which was conspicuous, according to Bessel, on the 2nd, it ceased, and no efflux was observed for several days. About the 8th, however, it recommenced more violently than before, and assumed a new form. At this time Schwabe noticed an appearance which he denominates a "second tail," presented in a direction opposed to that of the original tail, and, therefore, towards the sun. This appearance seems, however, to be regarded by Bessel merely as the renewed ejection of nebulous matter, which was afterwards turned back from the sun as smoke would be by a current of air blowing from the sun in the direction of the original tail.

From the 8th to the 22nd, the form, position, and brightness of the nebulous emanations underwent various and irregular changes, the last alternately increasing and decreasing.

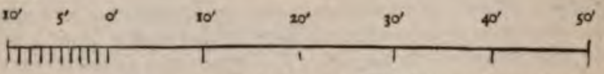
At one time two, at another three, nebulous emanations were observed to issue in divergent directions. These directions were continually varying, as well as their comparative brightness. Sometimes they would assume a swallow-tailed form, resembling the flame issuing from a fan gas-burner. The principal jet or tail was also observed to oscillate on the one side and the other of a line drawn from the sun through the centre of the head of the comet, exactly as a compass needle oscillates between the one and the other side of the magnetic meridian. This oscillation was so rapid, that the direction of the jets was visibly changed from hour to hour. The brightness of the matter composing them, being most intense at the point at which it seemed to be ejected from the nucleus, faded away as it expanded into the coma, curving backwards, in the direction of the principal tail, like steam or smoke before the wind.

629. **Struve's drawings of the comet approaching the sun in 1835.** — These curious phenomena will, however, be more clearly conceived by the aid of the admirable drawings of M. Struve, which we have reproduced with all practicable fidelity, in

Plates XXIV. XXV. and XXVI. These drawings were executed by M. Kruger, an eminent artist, from the immediate observation of the appearances of the comet with the great Fraunhofer telescope, at the Pulkowa Observatory. The sketches of the artist were corrected by the astronomer, and only adopted definitively after repeated comparisons with the object. The original drawings are preserved in the library of the observatory.

630. **Its appearance on September 29th.**—Plate XXIV. *fig.* 1, represents the appearance of the comet on the 29th of September. The tail was difficult to be recognised, appearing to be composed of very feeble nebulous matter. The nucleus passed almost centrically over a star of the 10th magnitude, without in the slightest degree affecting its apparent brightness. The star was distinctly seen through the densest part of the comet. Another transit of a star took place with a like result.

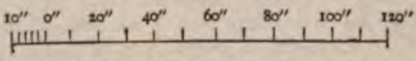
Annexed is the scale according to which this drawing has been made.



631. **Appearance on October 3.**—This is represented in *fig.* 2, on the same scale.

The comet changed not only its magnitude and form, but also its position since September 29. On that day the direction of the tail was that of the parallel of declination through the head. On October 3, it was inclined from that parallel towards the north at a small angle, and, instead of being straight, was curved. The diameter of the head was increased in the ratio of 2 to 3, and the length of the tail in the ratio of nearly 1 to 3.

632. **Appearance on October 8.**—Plate XXV. *fig.* 1. This drawing is made on the subjoined scale of seconds.



On the 5th, 6th, and 7th the comet underwent several changes: the nucleus became more conspicuous. On the 6th, a fan-formed flame issued from it, which disappeared on the 7th, and reappeared on the 8th with increased splendour, as represented in the figure. The nucleus appeared like a burning coal, of oblong form, and yellowish colour. The extent of the flame-like emanation was about 30″. The feeble nebula surrounding the nuclei extended much beyond the limits of the drawing, but, being overpowered by the moonlight, could not be measured.

633. **Appearance on October 9.**—Plate XXV. *fig.* 2, same scale, represents the nucleus and flame-like emanation, which

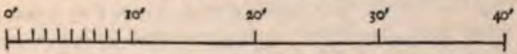
entirely changed their form and magnitude since the preceding night. The tail (not included in the drawing) measured very nearly 2°. The flame consisted of two parts, one resembling that seen on the 8th, and the other issuing like the jet from a blow-pipe in a direction at right angles to it. The figure represents the nucleus and flame as they appeared at 21^h sid. time, with a magnifying power of 254.

634. **Appearance on October 10.**—Plate XXV. *fig.* 3, on the same scale. The tail, which still measured nearly 2°, was now much brighter, being visible to the naked eye, notwithstanding strong moonlight. The coma was evidently broader than the tail. The flaming nucleus is represented in the drawing as it appeared under a magnifying power of 86, with a field of 18′ diameter, the entire of which was filled with this coma. The diameter of the latter must, therefore, have been more than 18′. The drawing was taken at 21*h.* sidereal time.

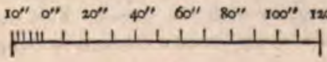
635. **Appearance on October 12.**—Plate XXV. *fig.* 4, on the same scale. The comet appeared at $0^h\ 25^m$ sid. time for a short interval in uncommon splendour, the nucleus and flame, however, alone being visible, as represented in the drawing. The greatest extent of the flame measured 64″·7. Its appearance was most beautiful, resembling a jet streaming out from the nucleus, like flame from a blow-pipe, or the flame from the discharge of a mortar, attended with the white smoke driven before the wind.

636. **Appearance on October 14.**—Plate XXV. *fig.* 5, on the same scale. The principal flame was now greatly enlarged, extending to the apparent length of 134″. Its deflection and curved form were most remarkable.

637. **Appearance on October 29.**—A cloudy sky prevented all observation for 12 days. On the 27th, the comet appeared to the naked eye as bright as a star of the third magnitude, the tail being distinctly visible. The coma surrounding the nucleus appeared as a uniform nebula. The tail was curved and of great length; but, owing to the low altitude at which the observation was taken, it could not be measured. On the 29th, however, the comet was presented under much more favourable conditions, and the drawings, Plate XXIV. *fig.* 3, and Plate XXVI. *fig.* 1, were made. The former represents the entire comet, including the whole visible extent of the tail, and is drawn to the annexed scale of

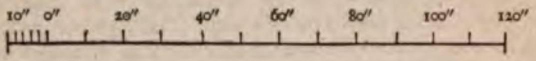


minutes. The latter represents the head of the comet only, and is drawn to the annexed scale of seconds.



At $20^h\ 30^m$ sidereal time, the head presented the appearance represented in Plate XXVI. *fig.* 1. The chief coma was almost exactly circular, and had a diameter of 165″. With a power of 198, the nucleus appeared as in the figure, the diameter being about 1″·25 to 1″·50. The flame issuing from the nucleus, curved back like smoke before the wind, was very conspicuous. The appearance of the formation of the tail as it issues from the nucleus was remarkably developed.

638. **Appearance on November 5.**—Plate XXVI. *fig.* 2. This drawing represents the nucleus and flame issuing from it on the annexed scale of seconds.



The proper nucleus was found to measure about 2″·3. Two flames were seen issuing from it in nearly opposite directions, and both curved towards the same side. The brighter flame, directed towards the north, was marked by strongly defined edges. The other, directed towards the south, was more feeble and ill-defined.

639. **Sir J. Herschel's deductions from these phenomena.**—Sir J. Herschel, who also observed this comet himself at the Cape of Good Hope, makes from all these observations the following inferences.

1. That the matter of the comet vaporised by the sun's heat escapes in jets, throwing the comet into irregular motion by its reaction, and thus changing its own direction of ejection.

2. That this ejection takes place principally from the part presented to the sun.

3. That thus ejected, it encounters a resistance from some unknown force by which it is repulsed in the opposite direction, and so forms the tail.

4. That this acts unequally on the cometary matter, which is not all vaporised, and of that which is a considerable portion, is retained so as to form the head and coma.

5. That this force cannot be solar gravitation, being contrary to that in its direction, and very much greater in its intensity, as is manifest by the enormous velocity with which the matter of the tail is driven from the sun.

6. That the matter thus repelled to a distance so great, from a body whose mass is so small, must to a great extent escape from the feeble influence of the gravitation of the mass composing the head and coma, and, unless there be some more active agency in operation, a large portion of such vaporised matter must be lost in space, never to reunite with the comet. This would lead to the consequence, that at every passage through its perihelion the comet

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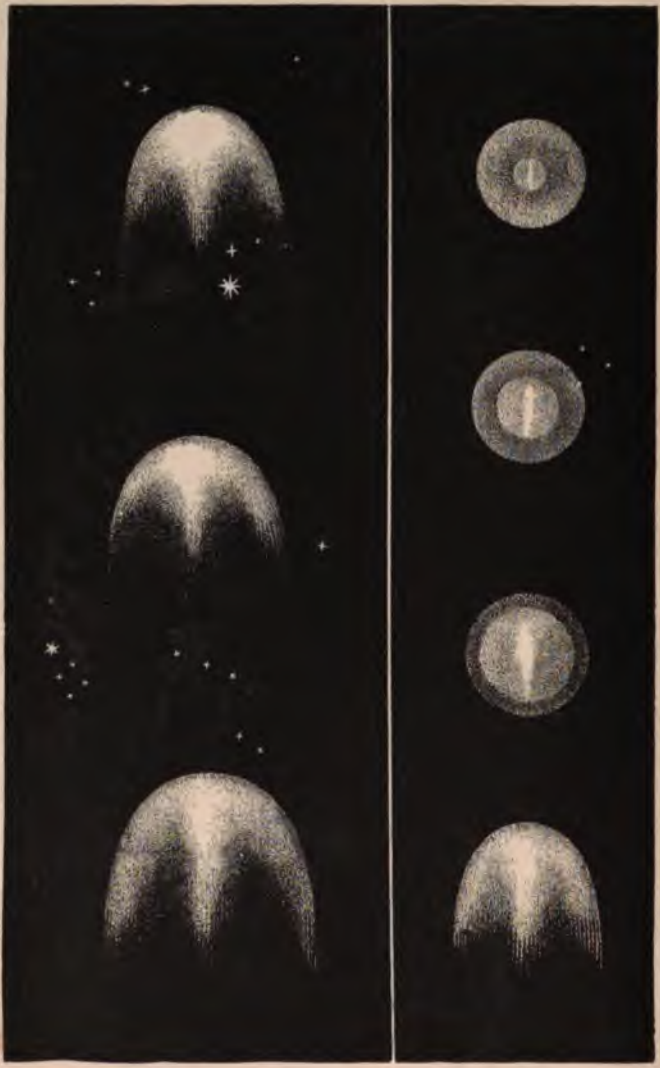

HALLEY'S COMET DEPARTING FROM THE SUN IN 1836.

Telescopic views by Messrs. Maclear and Smyth.

1. Jan. 24. 2. Jan. 25. 3. Jan. 26. 4. Jan. 27. 5. Jan. 28. 6. Jan. 30. 7. Feb. 1.

[redacted]

XXVIII.

1 3

2 4

HALLEY'S COMET DEPARTING FROM THE SUN IN 1836.

Telescopic views by Messrs. Maclear and Smyth.

1. Feb. 7. 2. Feb. 10. 3. Feb. 16. 4. Feb. 25

would lose more and more of its vaporisable constituents, on which the production of the coma and tail depends, so that, at each successive return, the dimensions of these appendages would be less and less, as they have in fact been found to be.

640. **Appearance of the comet after perihelion.**—On receding from the sun after its perihelion, the comet was observed under very favourable circumstances at the Cape by Sir J. Herschel and Mr. Maclear. It first reappeared there on the 24th of January, under an aspect altogether different from that under which it was seen before its perihelion. It had evidently, as Sir J. Herschel thinks, undergone some great physical change, which had operated an entire transformation upon it.

"Nothing could be more surprising than the total change which had taken place in it since October. . . . A new and unexpected phenomenon had developed itself, quite unique in the history of comets. Within the well-defined head, somewhat excentrically placed, was a vivid nucleus resembling a miniature comet, with a head and tail of its own, perfectly distinct from and considerably exceeding in intensity the nebulous disk or envelope which I have above called the 'head.' A minute bright point, like a small star, was distinctly perceived within it, but which was never quite so well defined as to give the positive assurance of the existence of a solid sphere, much less could any phase be discerned."

641. **Observations and drawings of Messrs. Maclear and Smyth.**—The phenomena and changes which the comet presented from its reappearance on the 24th of January, until its final disappearance, have been described with great clearness by Mr. Maclear, and illustrated by a beautiful series of drawings by that astronomer and his assistant, Mr. Smyth, in a memoir which appeared in the tenth volume of the *Transactions of the Royal Astronomical Society*, from which we reproduce the series of illustrations given on Plates XXVII. and XXVIII.

642. **Appearance on January 24.**—The comet appeared, as in *fig.* 1, visible to the naked eye as a star of the second magnitude. The head was nearly circular, and presented a pretty well-defined planetary disk, encompassed by a coma or halo of delicate gossamer-like brightness. The diameter of the head, without the halo or coma, measured 131″, and with the latter 492″.

643. **Appearance on January 25.**—*Fig.* 2. Circular form broken, and magnitude increased. Three stars seen through the coma, and one through the head.

644. **Appearance on January 26.**—*Fig.* 3. Magnitude again increased, but coma diminished.

* *Cape Observations*, p. 397.

645. **Appearance on January 27.** — *Fig.* 4. Comet began to assume the parabolic form, and increase of magnitude continued.

646. **Appearance on January 28.** — *Fig.* 5. The coma or halo quite invisible, but the nucleus appeared like a faint small star. The magnitude of the comet continued to increase. The observer fancied he saw the faint outline of a tail.

647. **Appearance on January 30.** — *Fig.* 6. The form of the comet now became decidedly parabolic. The breadth across the head was 702″, being greater than on the 24th in the ratio of 49 to 70, or 7 to 10, which corresponds to an increase of volume in the ratio of 1 to 3, supposing the form to remain unchanged; but it was estimated that the extension in length gave a superficial increase in the ratio of 35 to 1, which would correspond to a much greater augmentation of volume.

648. **Appearance on February 1.** — *Fig.* 7. Further increase of magnitude, the form remaining the same.

649. **Appearance on February 7.** — Plate XXVIII. *fig.* 1. The comet was on this night rendered faint by the effect of moonlight.

650. **Appearance on February 10.** — *Fig.* 2. Further increase of volume. A star visible through the body of the comet.

651. **Appearance on February 16 and 23.** — *Figs.* 3, 4. The magnitude went on increasing, while the illumination became more and more faint, and this continued until the comet's final disappearance; the outline, after a short time, became so faint as to be lost in the surrounding darkness, leaving a bland nebulous blotch with a bright centre enveloping the nucleus.

652. **Number of comets.**—According to Mr. Hind, the number of comets which have appeared since the birth of Christ in each successive century is as follows: I., 22.; II., 23.; III., 44.; IV., 27.; V., 16.; VI., 25.; VII., 22.; VIII., 16.; IX., 42.; X., 26.; XI., 36.; XII., 26.; XIII., 26.; XIV., 29.; XV., 27.; XVI., 31.; XVII., 25.; XVIII., 64.; XIX. (first half), 80. Total, 607.

Since the beginning of the second half of the present century, a period of ten years, no less than 31 new comets have been discovered; this arises most probably from the great precision of modern astronomical instruments, added to the zeal and devotion shown by astronomers since 1845, in endeavouring to increase our knowledge by the discovery of new members of our planetary and cometary systems.

653. **Duration of the appearance of comets.** —Since comets are visible only near their perihelia, when their velocity is greatest, the duration of their visibility at any single perihelion passage is generally short. The longest appearance on record is

that of the great comet of 1811, which continued to be visible for 510 days. The comet of 1825 was visible for twelve months, and others which appeared since have been seen for eight months. In general, however, these bodies do not continue to be seen for more than two or three months.

654. **Near approach of comets to the earth.**—Considering the vast numbers of comets which have passed through the system, such an incident as the collision of one of them with a planet might seem no very improbable contingency. Lexell's comet was supposed to have passed among the satellites of Jupiter; and, if that were the case, it is certain that the motions of these bodies were not in the least affected by it. One of the nearest approaches to the earth ever made by a comet was that of the comet of 1684, which came within 216 semi-diameters of the earth, a distance not so much as four times that of the moon. The brilliant comet of 1861 approached very near to the earth on July 30. Its tail was supposed to envelop our globe on that day, or at least, to have been at a very short distance from us.

CHAPTER XIX.

THE FIXED STARS.—MAGNITUDE AND LUSTRE.

655. **Creation not circumscribed by the solar system.**—The region of space, vast as it is, which is occupied by the solar system, forms but a small portion of that part of the material universe to which scientific inquiry and research have been extended. The inquisitive spirit of man has not rested content within such limits. Taking its stand at the extremities of the system, and throwing its searching glance toward the interminable realms of space which extend beyond them, it still asks—What lies there? Has the Infinite circumscribed the exercise of his creative power within these precincts—and has He left the unfathomable depths of space that stretch beyond them a wide solitude? Has He whose dwelling is immensity, and whose presence is everywhere and eternal, remained inactive throughout regions compared with which the solar system shrinks into a point?

Even though scientific research should have left us without definite information on these questions, the light which has been shed on the Divine character, as well by reason as by revelation, would have filled us with the assurance that there is no part of space however remote, which must not teem with evidences of exalted power, inexhaustible wisdom, and untiring goodness.

But science has not so deserted us. It has, on the contrary, supplied us with much interesting information respecting regions of the universe, the extent of which is so great that even the whole dimensions of the solar system supply no modulus sufficiently great to enable us to express their magnitude.

656. **The solar system surrounded by a vast but limited void.**— We are furnished with a variety of evidence, establishing incontestably the fact, that around the solar system to a vast distance on every side there exists an unoccupied space; that the solar system stands alone in the midst of a vast solitude. It has been shown, that the mutual gravitation of bodies placed in the neighbourhood of each other, is betrayed by its effects upon their motions. If, therefore, there exists beyond the limits of the solar system, and within a distance not so great as to render the attraction of gravitation imperceptible, any mass of matter, such as another sun like our own, such a mass would undoubtedly exercise a disturbing force upon the various bodies of the system. It would cause each of them to move in a manner different from that in which it would have moved if no such body existed.

Thus it appears that, even though a mass of matter in our neighbourhood should escape direct observation, its presence would be inevitably betrayed by the effects which its gravitation would produce upon the planets. No such effects, however, are discoverable. The planets move as they would move if the solar system were independent of any external disturbing attraction. These motions are such, and such only, as can be accounted for by the attraction of the sun and the reciprocal attraction of the other bodies of the system. The inference from this is, that there does not exist any mass of matter in the neighbourhood of the solar system within any distance which permits such a mass to exercise upon it any discoverable disturbing influence; and that if any body analogous to our sun exists in the universe, it must be placed at a distance so great, that the whole magnitude of our system will shrink into a point, compared with it.

657. **Orders of magnitude of the stars.**—Among the multitude of stars dispersed over the firmament, we find a great variety of splendour. Those which are the brightest and largest, and which are said to be of the *first magnitude*, are few; the next in order of brightness, which are called of the *second magnitude*, are more numerous; and as they decrease in brightness their number rapidly increases.

The number of stars of the first magnitude does not exceed twenty-four; the second, fifty; the third, two hundred; and so on, the number of the smallest visible without a telescope being from 12,000 to 15,000.

The stars which are capable of being seen by the naked eye are usually resolved into seven orders of magnitude—the first being the brightest and largest, while those of the seventh magnitude are the smallest that the eye can distinctly see.

658. **These varieties of magnitude caused chiefly by difference of distance.**—Are we to suppose, then, that this relative brightness which we perceive, really arises from any difference of intrinsic splendour between the objects themselves? or does it, as it may equally do, arise from their difference of distance? Are the stars of the seventh magnitude so much less bright and conspicuous than those of the first magnitude, because they are really smaller orbs placed at the same distance? or because being intrinsically equal in splendour and magnitude, the distance of those of the seventh magnitude is so much greater than the distance of those of the first magnitude that they are diminished in their apparent brightness? We know that by the laws of optics the light received from a luminous object diminishes in a very rapid proportion as the distance increases. Thus at double the distance it will be four times less, at triple the distance it will be nine times less, at a hundred times the distance it will be ten thousand times less, and so on.

It is evident, then, that the great variety of lustre which prevails among the stars may be indifferently explained, either by supposing them objects of different intrinsic brightness and magnitude, placed at the same distance; or objects generally of the same order of magnitude, placed at a great diversity of distances.

Of these two suppositions, the latter is infinitely the more probable and natural; it has, therefore, been usually adopted: and we accordingly consider the stars to derive their variety of lustre almost entirely from their places in the universe being at various distances from us.

659. **Stars as distant from each other generally as they are from the sun.**—Taking the stars generally to be of intrinsically equal brightness, various theories have been proposed as to the positions which would explain their appearance; and the most natural and probable is, that their distances from each other are generally equal, or nearly so, and correspond with the distance of our sun from the nearest of them. In this way the fact that a small number of stars only appear of the first magnitude, and that the number increases very rapidly as the magnitude diminishes, is easily rendered intelligible.

660. **Why stars increase in number as they decrease in magnitude.**—If we imagine a person standing in the midst of a wood, surrounded by trees on every side, and at every distance, those

which immediately surround him will be few in number, and by proximity will appear large. The trunks or stumps of those which occupy a circuit beyond the former, will be more numerous, the circuit being wider, and will appear smaller, because their distance is greater. Beyond these again, occupying a still wider circuit, will appear a proportionally augmented number, whose apparent magnitude will again be diminished by increased distance; and thus the trees which occupy wider and wider circuits at greater and greater distances will be more and more numerous, and will appear continually smaller. It is the same with the stars; we are placed in the midst of an immense cluster of suns, surrounding us on every side at inconceivable distances. Those few which are placed immediately about our system, appear bright and large, and we call them *stars of the first magnitude.* Those which lie in the circuit beyond, and occupy a wider range, are more numerous and less bright; and we call them *stars of the second magnitude.* And there is thus a progression increasing in number and distance and diminishing in brightness until we attain a distance so great that the stars are barely visible to the naked eye. This is the limit of vision. It is the limit of the range of the eye in its natural condition; but an eye has been given us more potent still, and of infinitely wider range,—the eye of the mind. The telescope, a creature of the understanding, has conferred upon the bodily eye an infinitely augmented range, and, as we shall presently see, has enabled us to penetrate into realms of the universe, which, without its aid, would never have been known to us. But let us pause for the present, and dwell for a moment upon that range of space which comes within the scope of natural vision.

661. **What are the fixed stars?**—The extent of the stellar universe visible to the naked eye, and the arrangement of stars in it and their relative distances, have just been explained. But curiosity will be awakened to discover, not merely the position and arrangement of those bodies, but to ascertain what is their nature, and what parts they play on the great theatre of creation. Are they analogous to our planets? Are they inhabited globes, warmed and illuminated by neighbouring suns? Or, on the other hand, are they themselves suns, dispensing light and life to systems of surrounding worlds?

662. **Telescopes do not magnify them like the planets.**—When a telescope is directed to a star, the effect produced is strikingly different from that which we find when it is applied to a planet. A planet to the naked eye, with one or two exceptions, appears like a common star. The telescope, however, immediately presents it to us with a distinct circular disk similar to that which the moon offers to the naked eye, and in the case of some of the

planets a powerful telescope will make them appear of considerable magnitude. But the effect is very different indeed when the same instrument is directed even to the brightest star. We find that instead of magnifying, it actually diminishes. There is an optical illusion produced when we behold a star, which makes it appear to us to be surrounded with a radiation which causes it to be represented when drawn on paper, by a dot with rays diverging on every side from it. The effect of the telescope is to cut off this radiation, and present to us the star as a mere *lucid point*, having no sensible magnitude; nor can any augmented telescopic power which has yet been resorted to, produce any other effect. Telescopic powers amounting to six thousand were occasionally used by Sir William Herschel, and he stated that with these the apparent magnitude of the stars seemed *less*, if possible, than with lower powers.

663. **The absence of a disk proved by their occultation by the moon.** — We have other proofs of the fact that the stars have no sensible disks, among which may be mentioned the remarkable effect called the occultation of a star by the dark edge of the moon. When the moon is a crescent or in the quarters, as it moves over the firmament, its dark edge successively approaches to, or recedes from the stars. And from time to time it happens that it passes between the stars and the eye. If a star had a sensible disk in this case, the edge of the moon would gradually cover it, and the star, instead of being instantaneously extinguished, would gradually disappear. This is found not to be the case; the star preserves all its lustre until the moment it comes into contact with the dark edge of the moon's disk, and then it is instantly extinguished, without the slightest appearance of diminution of its brightness.

664. **Meaning of the term magnitude as applied to stars.** —It may be asked then, if such be the case, if none of the stars, great or small, have any discoverable magnitude at all, with what meaning can we speak of stars of the first, second, or other orders of magnitude? The term magnitude thus applied, was used before the invention of the telescope, when the stars, having been observed only with the naked eye, were really supposed to have different magnitudes. We must accept the term now to express, not the comparative magnitude, but the comparative brightness of the stars. Thus a star of the first magnitude, means of the greatest apparent brightness; a star of the second magnitude, means that which has the next degree of splendour, and so on. But what are we to infer from this singular fact, that no magnifying power, however great, will exhibit to us a star with any sensible magnitude? must we admit that the optical instrument loses its magnifying power when applied to the stars, while it retains it with every other visible object?

Such a consequence would be eminently absurd. We are therefore driven to an inference regarding the magnitude of stars, as astonishing and almost as inconceivable as that which was forced upon us respecting their distances. We saw that the entire magnitude of the annual orbit of the earth, stupendous as it is, was nothing compared to the distance of one of those bodies, and consequently if that orbit were filled by a sun, whose magnitude would therefore be infinitely greater than that of ours, such a sun would not appear to an observer at the nearest star of greater magnitude than 1″; consequently it would have no magnitude sensible to the eye, and would appear as a mere lucid point to an observer at the star! We are then prepared for the inference respecting the fixed stars which telescopic observations lead to. The telescope of Sir William Herschel, to which he applied a power of six thousand, did undoubtedly magnify the stars six thousand times, but even then their apparent magnitude was inappreciable. We are then to infer that the distance of these wonderful bodies is so enormous compared with their actual magnitude, that their apparent diameter, seen from our system, is above six thousand times less than any which the eye is capable of perceiving.

665. **Why stars may be rendered imperceptible by their distance.**—It appears, therefore, that stars are rendered sensible to the eye, not by subtending a sensible angle, but by the light they emit. An illuminated or luminous object, such for example as the sun, has the same apparent brightness at all distances, and consequently, the quantity of light which the eye of an observer receives from it being in the exact ratio of the apparent area of its visual disk, is inversely as the square of its distance. It remains, however, to be explained how it can be that, after it ceases to have a disk of sensible diameter, it does not cease to be visible. This arises from the fact that the luminous point constituting the image on the retina is intrinsically as bright as when that image has a large and sensible magnitude. The eye is therefore sensible to the light, though not sensible to the magnitude of the image; and it continues to be sensible to the light, until by increase of distance, the light which enters the pupil and is collected on the retina, though still as intense in its brilliancy as before, is so small in its *quantity*, that it is insufficient to produce sensation.

666. **Classification of stars by magnitudes arbitrary and insufficient.**—The distribution of the stars visible to the naked eye into seven orders of magnitude, has been so long and so generally received, and is referred to so universally in the works of astronomers, ancient and modern, that it would be impossible altogether to supersede it, and if possible, such a change would be attended with great inconvenience. Nevertheless, this classification is open to many

objections, and is, from its looseness and want of definiteness and precision, in singular discordance with the actual state of astronomical science. The stars which abound in such countless numbers on the firmament, are of infinite gradations, from that of Sirius, the most splendid object of this class, to the most faint stars which the sharpest and most practised eye can distinguish on the darkest and clearest night. To distribute such a series so imperceptibly decreasing in splendour, into seven orders of magnitude, must obviously be an arbitrary process, in which no two observers could possibly agree. There are no natural breaks of continuity by which the stars of the first magnitude could be separated from those of the second, the second from those of the third, and so on. Whatever be the stars assigned to any class, the brightest will be undistinguishable from the faintest of those of the next superior magnitude, and the faintest will be equally undistinguishable from the brightest of the next inferior magnitude.

The stars assigned to any order of magnitude, must in such a classification differ greatly one from another in brightness. Thus, of the 24 or 25 stars that are usually assigned to the first magnitude in the received classification, Sirius, the brightest, is about four times as bright as α Centauri, which may be taken as the type of the average brightness of stars of this magnitude.

667. **Importance of more exact astrometric expedients.** — When it is considered that the exact ratio of the apparent lustre of the stars, combined with their parallaxes when the latter are known, supplies the data by which the absolute splendour of these bodies may, as will presently appear, be calculated; and further, that they may be thus brought into immediate numerical comparison with the sun, which is itself only an individual of the same class of bodies, the importance of the expedients for the more exact estimation of their relative lustre, and a more precise basis of classification as to apparent magnitude, cannot fail to be felt and acknowledged. The importance of this is rendered still greater by the consideration that the parallax of a very small number of stars being found to have appreciable magnitude, the comparative lustre of these bodies taken in the mass is the only ground upon which any estimate of their relative distances can be determined; and when the large number which are subject to observation is considered, and the improbability of their differing greatly in intrinsic magnitude taken collectively in classes, it must be admitted that their relative apparent brightness cannot fail to be a tolerably exact exponent of their comparative distances.

668. **Astrometer contrived and applied by Sir J. Herschel.** — During his residence at the Cape, Sir J. Herschel contrived an

apparatus for the more exact determination of the relative lustre of the stars, and applied it with great advantage to the determination of the relative brightness of a considerable number of these objects. This apparatus consisted of a rectangular glass prism, and a lens so mounted that two celestial objects might be seen in juxtaposition, one directly, and the other by reflection and transmission through the prism and lens, the apparent brightness of the latter being capable of being varied at pleasure by the observer, so that, by proper adjustments, the two objects thus seen may be rendered sensibly equal in brightness. When this is accomplished, the arrangements of the apparatus are such, that by measuring the distance of the eye of the observer from the focus of the lens, a measure may be obtained, by which the comparative lustre of any objects to which the apparatus may be successively directed may be determined.

To render this intelligible, let P, *fig.* 96, represent the rectangular prism, one of the faces of which is placed so as to receive

Fig. 96.

a pencil of rays passing from a distant object J perpendicularly upon it. These rays are totally reflected (O. 120) by the back of the prism at P, and emerging from the other face of the prism, are received upon the lens L, and brought to a focus F, as if they came from the direction P F. The parallel pencil is thus converted into a divergent pencil, of which F is the focus, and the point F will appear to an eye, placed anywhere, as at E, within the limits of the divergent pencil as a star, the apparent brightness of which will be more or less according as the eye is nearer to or more distant from F. It results from the principles of optics, that the apparent brightness of the focal point F will be inversely as the square of the distance E F of the eye from this point. If, then, M express the apparent lustre of F when the eye is at the unit of

distance from it, M divided by D^2 will express its apparent lustre when the eye is at the distance D.

Let us now suppose the apparatus so arranged in its position that while the eye, placed within the divergent pencil, sees the focus F, it may also see, in juxtaposition with it, a star S, whose lustre is to be determined. Let the eye be moved to or from F until the lustre of the star becomes sensibly equal to that of F. If, then, the lustre of the star be expressed by S, we shall have

$$S = \frac{M}{D^2}.$$

Let the apparatus be then directed to another star, whose lustre S' is to be compared with the former, and let the same operation be repeated, the distance of the eye from F being so regulated as to render the apparent lustre of the point F equal to that of the second star. The distance of the eye from F being, in this case, expressed by D', we shall then have

$$S' = \frac{M}{D'^2};$$

and consequently,

$$\frac{S}{S'} = \frac{D'^2}{D^2};$$

that is to say, the apparent lustres of the two stars are in the inverse numerical ratio of the squares of the distances of the eye from F, which would render the apparent lustre of F equal to those of the stars respectively.

In the series of observations made at the Cape by Sir J. Herschel, the moon was the object with which the stars were thus compared. The planet Jupiter would, perhaps, be more convenient; but any object which would retain an invariable brightness during the short interval necessary for the comparison of the stars under observation would serve the purpose.

In this manner, Sir J. Herschel ascertained numerically the comparative brightness of a considerable number of stars of greater magnitude than the fourth, and has given, in his "*Cape Observations*," a catalogue, exhibiting the relative magnitudes to two places of decimals.

669. **Principle on which the successive orders of stellar magnitude should be based.**—Astronomers are not agreed as to the optical conditions by which the successive orders of stellar magnitudes should be fixed. It might appear, at first view, that a star of the second magnitude ought to have one-half the brightness of one of the first magnitude, that a star of the third magnitude ought to have one-third of the brightness, and so on.

But such a proportion would not be at all in accordance with the common classification of magnitudes.

The more generally received condition has been a succession of magnitudes, such as a star of a given intrinsic lustre would have if removed to a series of distances increasing in arithmetical progression. Thus, stars of the first magnitude would be at the unit of stellar distance; those of the second magnitude would have a lustre due to twice this distance; those of the third magnitude, to three times this distance, and so on. Now, since the apparent lustre of an object is in the proportion of the inverse square of the distance, it would follow that, in this system the succession of brightness would be as the numbers $1, \frac{1}{4}, \frac{1}{9}, \frac{1}{16}$, and so on.

Meanwhile, whatever may be the principle adopted for this classification, the astrometric expedient contrived by Sir John Herschel being sufficient for the numerical estimation of the relative brightnesses of different stars, it will be sufficient to determine a variety of interesting and important problems respecting the absolute lustre and magnitudes of those objects, not only compared with each other, but with the sun.

670. **Comparative lustre of α Centauri with that of the full moon.** — By means of the instrument described above, Sir J. Herschel compared the full moon with certain fixed stars, and ascertained, by a mean of eleven observations, that its lustre bore to that of the star α Centauri which he selected as the standard star of the first magnitude, the ratio of 27,408 to 1; in other words, he showed that a cluster consisting of 27,408 stars equal in brightness to that of α Centauri would give the same light as the full moon.

671. **Comparison of the lustre of the full moon with that of the sun.** — Dr. Wollaston by certain photometric methods which are considered to have been susceptible of great precision, compared the light of the sun with that of the full moon, and found that the ratio was 801,072 to 1; or in other words, that to obtain moon-light as intense in its lustre as sun-light, it would be necessary that 801,072 full moons should be stationed in the firmament together.

672. **Comparison of the sun's light with that of α Centauri.** — By the combination of these observations of Herschel and Wollaston, we are supplied with means of bringing into direct numerical comparison the sun and the star α Centauri. Since it appears that the light of α Centauri is 27,408 times less than that of the full moon, while the light of the full moon is 801,072 times less than that of the sun, it will evidently follow, that the light of the sun is very nearly 22,000,000,000 times more intense than that of α Centauri.

673. **Comparison of the intrinsic splendour of the sun and a fixed star.** — Since all analogy and observation lead to the conclusion, that the stars, like the sun, are self-luminous bodies, although no telescopic power which we can command can exhibit them with a sensible disk, it cannot be doubted that they are, like the sun, spherical bodies. If then, I express the intrinsic brightness, or what is the same, the absolute quantity of light emitted by a superficial unit of the visible surface of such a sphere, and if M express the superficial magnitude of the hemisphere presented to the eye, the total quantity of light emitted, or total intrinsic lustre, will be expressed by $I \times M$. But the apparent lustre will, according to the common optical law, decrease as the square of the distance of the observer increases, and consequently, if $I \times M$ express the lustre at the unit of distance, $I \times \frac{M}{D^2}$, will express it at the distance D, so that we shall have

$$I \times M = L \times D^2.$$

If the apparent lustre, and the distance of the star, therefore, be both known, the intrinsic lustre, which depends conjointly upon the magnitude of the luminous surface exposed to view and its intrinsic brightness, will be known.

674. **Astrometer suggested by Dr. Lardner.** — To bring a fixed star into immediate comparison with the sun, and to obtain a measure of the visual magnitude of the star, supposing it to have an intrinsic lustre equal to that of the sun, would be easy if the distance could be ascertained to which it would be necessary to remove the sun, so that it shall present to the eye the same apparent lustre as the star, for in that case the visual magnitude of the sun, which could be calculated by means of its real magnitude and distance, would necessarily be equal to the visual magnitude of the star. In this manner, a visual angle too small to be ascertained by direct instrumental measurement, would be determined by indirect means.

Let d = the real diameter of the sun, D = the distance to which it would be necessary to remove it from the observer, so that it might present to the eye the same appearance as a given star, and let ϕ = its visual diameter at that distance. We should then have,

$$\phi'' = 206265 \times \frac{d}{D},$$

and ϕ would then be the visual angle subtended by the star, if the star be supposed to have the same intrinsic lustre as the sun. But if the star be supposed to have a greater or less intrinsic lustre than the sun, then the visual magnitude of the star will be greater or less than ϕ.

Although the sun cannot be removed to increased distances, the same optical effect may be produced by the following expedient.

Let A B C D be a tube like that of a telescope, furnished with a diaphragm at B C, so constructed that by sliding pieces, a circular

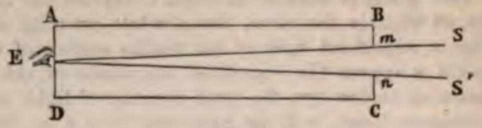

Fig. 97.

aperture, having a diameter variable at pleasure within practicable limits, may be made in its centre. Let a sliding tube having an eye-hole in a diaphragm at the end of it, like that in the eye-piece of a telescope, be attached to the other end A D of the tube, so that the distance of the eye-hole from the variable aperture *m n* may be varied at pleasure within practicable limits. It is evident, that the diameter of the aperture *m n*, and the distance from the eye at E to *m n* being known, the visual angle subtended by *m n* at E will be determined.

If the tube thus constructed and arranged be directed to the disk of the sun, a circular part of that disk having any desired visual diameter can be made visible to the eye placed at E. This can always be accomplished within limits by the variation of the diameter *m n* of the aperture, and the variation of the distance of the eye E from *m n*.

But, by a well-understood principle of optics (O. 364), the circular part of the sun's disk visible through the aperture has exactly the same appearance, both in apparent magnitude and brightness, as the sun itself would have if it were removed to such a distance from the observer, that it would subtend the same visual angle as that subtended by the aperture *m n* at the eye E.

If then the apparatus be so adjusted, that the apparent lustre of the part of the sun seen through the aperture shall be equal, as exactly as can be determined by an observation of this kind, to the apparent brightness of any star, it will follow, that the visual angle subtended by the aperture seen from E, will be equal to the visual angle subtended by the star; and as the former can be calculated by knowing the real diameter of the aperture and its distance from E, the latter can be inferred.

In the practical application of this method, the difficulty arises from not being able to bring the luminous point seen in the tube into immediate juxtaposition with the star with which it is compared. The observer must rely upon his judgment and memory

of the apparent brightness of the stars, to determine when that of the luminous point seen in the tube is equal to it.

675. **Astrometric table of 190 principal stars.**—In the following table are collected the results of the observations of Sir J. Herschel, for the determination of the relative lustre of 190 principal stars. In addition to their astrometric magnitudes, as determined by Sir J. Herschel, we have computed from the data supplied by him, their relative brightness compared with that of the star α Centauri as a standard, and also their light in billionths of the light of the sun.

TABLE.

List of 190 stars, from the first to the third magnitude inclusive, with their magnitudes, according to the astrometric scale proposed by Sir John Herschel; and their apparent brightness compared with each other, and with the sun.

Name of Star.	Astrometric Magnitude.	Star's Light.	
	α Centauri = 1.	α Centauri = 1.	Billionths of Sun's Light.
I. First Mag.			
Sirius	0·49	4·165	189·7
Canopus	0·70	2·04	92·97
α Centauri	1·00	1·00	45·55
Arcturus	1·18	0·72	32·71
Rigel	1·23	0·66	30·11
Capella	1·40	0·51	23·24
α Lyræ	1·40	0·51	23·24
Procyon	1·40	0·51	23·24
α Orionis	1·43	0·49	22·27
α Eridani	1·50	0·44	20·24
Aldebaran	1·50	0·44	20·24
β Centauri	1·58	0·40	18·24
α Crucis	1·60	0·39	17·79
Antares	1·60	0·39	17·79
α Aquilæ	1·69	0·35	15·95
Spica	1·79	0·31	14·21
η Argûs	Variable.	—	—
II. 2 Mag.			
Fomalhaut	1·95	0·26	11·98
β Crucis	1·98	0·25	11·62
Pollux	2·00	0·25	11·39
Regulus	2·00	0·25	11·39
α Gruis	2·07	0·23	10·65
γ Crucis	2·14	0·22	9·95
ι Orionis	2·25	0·20	8·99
ε Canis maj.	2·27	0·194	8·84
λ Scorpii	2·28	0·192	8·78
α Cygni	2·31	0·187	8·54
Castor	2·35	0·181	8·25
ε Ursæ maj.	v. 2·36	0·179	8·18
α Ursæ maj.	v. 2·37	0·178	8·11
ζ Orionis	2·42	0·171	7·77
β Argûs	2·44	0·168	7·65
α Persei	2·48	0·163	7·41

Name of Star.	Astrometric Magnitude.	Star's Light.	
	α Centauri = 1.	α Centauri = 1.	Billionths of Sun's Light.
II. 2 Mag.			
γ Argûs	2·49	0·161	7·35
ε Argûs	2·59	0·149	6·79
η Ursæ maj.	v. 2·59	0·149	6·79
γ Orionis	2·59	0·149	6·79
α Triang. aust.	2·64	0·143	6·54
ε Sagittarii	2·67	0·140	6·39
β Tauri	2·69	0·138	6·29
Polaris	2·69	0·138	6·29
θ Scorpii	2·70	0·137	6·25
α Hydræ	2·71	0·136	6·20
δ Canis maj.	2·73	0·134	6·11
α Pavonis	2·74	0·133	6·07
γ Leonis	2·75	0·132	6·02
β Gruis	2·77	0·130	5·94
α Arietis	2·81	0·127	5·77
σ Sagittarii	2·82	0·126	5·73
δ Argûs	2·83	0·125	5·69
ζ Ursæ maj.	2·84	0·124	5·62
β Andromedæ	2·86	0·122	5·57
β Ceti	2·87	0·121	5·53
λ Argûs	2·87	0·121	5·53
β Aurigæ	2·89	0·120	5·45
γ Andromedæ	2·91	0·118	5·38
III. 3 Mag.			
γ Cassiopeiæ	2·93	0·116	5·32
α Andromedæ	2·95	0·115	5·25
θ Centauri	2·95	0·115	5·25
α Cassiopeiæ	2·98	0·113	5·13
β Canis maj.	2·99	0·112	5·09
κ Orionis	3·00	0·111	5·06
γ Geminorum	3·00	0·111	5·06
δ Orionis	3·02	0·110	4·99
Algol	v. 3·03	0·109	4·96
ε Pegasi	3·03	0·109	4·96

Name of Star.	Astrometric Magnitude. α Centauri = 1.	Star's Light. α Centauri = 1.	Billionths of Sun's Light.
III. 3 Mag.			
γ Draconis -	3·03	0·109	4·96
β Leonis -	3·04	0·108	4·93
α Ophiuchi -	3·04	0·108	4·93
β Cassiopeiæ -	3·04	0·108	4·93
γ Cygni - -	3·04	0·108	4·93
α Pegasi - -	3·06	0·107	4·86
β Pegasi - -	3·06	0·107	4·86
γ Centauri -	3·09	0·105	4·77
α Coronæ -	3·10	0·104	4·74
γ Ursæ maj. -	3·12	0·103	4·68
ε Scorpii -	3·12	0·103	4·68
ζ Argûs - -	3·13	0·102	4·65
β Ursæ maj. -	3·18	0·098	4·47
α Phœnicis -	3·19	0·098	4·47
ι Argûs - -	3·21	0·097	4·42
ε Boötis - -	3·21	0·097	4·42
α Lupi - -	3·23	0·096	4·37
ε Centauri -	3·23	0·096	4·37
η Canis maj. -	3·26	0·094	4·29
β Aquarii -	3·26	0·094	4·29
δ Scorpii -	3·27	0·0935	4·26
ε Cygni - -	3·29	0·0924	4·21
η Ophiuchi -	3·30	0·0918	4·18
γ Corvi - -	3·31	0·0913	4·16
α Cephei -	3·31	0·0913	4·16
η Centauri -	3·32	0·0907	4·13
α Serpentis -	3·33	0·0902	4·11
δ Leonis -	3·35	0·0891	4·06
κ Argûs - -	3·35	0·0891	4·06
β Corvi - -	3·36	0·0886	4·03
β Scorpii -	3·37	0·0881	4·01
ζ Centauri -	3·37	0·0881	4·01
ζ Ophiuchi -	3·38	0·0875	3·99
α Aquarii -	3·38	0·0875	3·99
π Argûs - -	3·39	0·0870	3·95
γ Aquilæ -	3·39	0·0870	3·95
δ Cassiopeiæ -	3·40	0·0865	3·94
δ Centauri -	3·40	0·0865	3·94
α Leporis -	3·41	0·0860	3·92
δ Ophiuchi -	3·41	0·0860	3·92
ζ Sagittarii -	3·42	0·0855	3·89
η Boötis - -	3·42	0·0855	3·89
η Draconis -	3·43	0·0850	3·87
π Ophiuchi -	3·46	0·0835	3·80
β Draconis -	3·47	0·0830	3·78
β Libræ - -	3·48	0·0826	3·76
γ Virginis -	3·49	0·0821	3·74
μ Argûs - -	3·49	0·0821	3·74
β Arietis -	3·50	0·0816	3·72
γ Pegasi -	3·52	0·0807	3·68
δ Sagittarii -	3·52	0·0807	3·68
α Libræ - -	3·53	0·0803	3·65
λ Sagittarii -	3·54	0·0798	3·63
β Lupi - -	3·55	0·0793	3·61
ε Virginis ? -	3·55	0·0793	3·61
α Columbæ -	3·56	0·0789	3·59
θ Aurigæ -	3·58	0·0780	3·55
β Herculis -	3·59	0·0776	3·53
ι Centauri -	3·61	0·0767	3·49
δ Capricorni -	3·61	0·0767	3·49
δ Corvi - -	3·63	0·0759	3·46
α Canum venat.	3·63	0·0759	3·46

Name of Star.	Astrometric Magnitude. α Centauri = 1.	Star's Light. α Centauri = 1.	Billionths of Sun's Light.
III. 3 Mag.			
β Ophiuchi -	3·64	0·0755	3·44
δ Cygni - -	3·65	0·0751	3·42
ε Persei - -	3·67	0·0742	3·38
η Tauri - -	3·67	0·0742	3·38
β Eridani -	3·67	0·0742	3·38
θ Argûs - -	3·67	0·0742	3·38
β Hydri - -	3·68	0·0738	3·36
ζ Persei - -	3·68	0·0738	3·36
ζ Herculis –	3·69	0·0734	3·34
ε Corvi - -	3·69	0·0734	3·34
ι Aurigæ -	3·70	0·0730	3·33
γ Ursæ min. -	3·71	0·0726	3·31
η Pegasi -	3·72	0·0723	3·29
β Aræ - -	3·72	0·0723	3·29
α Toucani -	3·73	0·0719	3·27
β Capricorni -	3·73	0·0719	3·27
ε Argûs - -	3·73	0·0719	3·27
ζ Aquilæ -	3·73	0·0719	3·27
β Cygni - -	3·74	0·0715	3·26
γ Persei - -	3·75	0·0711	3·24
μ Ursæ maj. -	3·75	0·0707	3·22
β Triang. bor.	3·76	0·0707	3·22
π Scorpii -	3·76	0·0707	3·22
β Leporis -	3·76	0·0707	3·22
γ Lupi - -	3·77	0·0704	3·21
δ Persei - -	3·77	0·0704	3·21
ψ Ursæ maj. -	3·77	0·0704	3·21
ε Aurigæ -	v. 3·78	0·0700	3·19
υ Scorpii -	*3·78	0·0700	3·19
ι Orionis -	3·78	0·0700	3·19
γ Lyncis -	3·80	0·0693	3·15
ζ Draconis -	3·81	0·0689	3·14
α Aræ - -	3·81	0·0689	3·14
π Sagittarii -	3·81	0·0689	3·14
π Herculis -	3·82	0·0685	3·12
β Can. min. ? -	3·82	0·0685	3·12
ζ Tauri - -	3·83	0·0682	3·10
δ Draconis -	3·83	0·0682	3·10
μ Geminorum	3·83	0·0682	3·10
γ Boötis - -	3·84	0·0678	3·09
ε Geminorum	3·84	0·0678	3·09
α Muscæ -	3·84	0·0678	3·09
α Hydri ? -	3·85	0·0675	3·07
τ Scorpii -	3·85	0·0675	3·07
δ Herculis -	3·85	0·0675	3·07
δ Geminorum	3·85	0·0675	3·07
π' Orionis -	3·86	0·0671	3·06
β Cephei -	3·86	0·0671	3·06
θ Ursæ maj. -	3·86	0·0671	3·06
ζ Hydræ -	3·86	0·0671	3·06
γ Hydræ -	3·87	0·0668	3·04
β Triang. aus.	3·87	0·0668	3·04
ι Ursæ maj. -	3·87	0·0668	3·04
η Aurigæ -	3·87	0·0668	3·04
γ Lyræ - -	3·88	0·0664	3·03
η Geminorum	3·89	0·0661	3·01
γ Cephei -	3·89	0·0661	3·01
κ Ursæ maj. -	3·90	0·0657	2·99
ε Cassiopeiæ -	3·90	0·0657	2·99
δ Aquilæ -	3·91	0·0654	2·98
σ Scorpii -	3·91	0·0654	2·98
τ Argûs - -	3·91	0·0654	2·98

676. **Use of the telescope in stellar observations.** — Since no telescope however great might be its power, has ever presented a fixed star with a sensible disk, it might be inferred that, for the purposes of stellar investigations, the importance of that instrument must be inferior to that which it may claim in other applications. Nevertheless it is certain, that in no department of physical science has the telescope produced such wonderful results, as in its application to the analyses of the starry heavens.

Two of the chief conditions necessary to distinct vision are, first, that the image on the retina shall have sufficient magnitude; or, what is equivalent to this, that the object or its image shall subtend at the eye a visual angle of sufficient magnitude (O. 349); and, secondly, it must be sufficiently illuminated (O. 329). When, by reason of their distance from the observer, visible objects fail to fulfil either or both of these conditions, the telescope is capable of re-establishing them. It augments the visual angle by substituting for the distant object, which the observer cannot approach, an optical image of it close to his eye, which he can approach; and it augments the illumination by collecting, on each point of such image, as many rays as can enter the aperture of the object glass, instead of the more limited number which can enter the pupil of the naked eye; the allowance, nevertheless, being made for the light lost by reflection from the surfaces of the lenses, and by the imperfect transparency of their material.

The increase of the visual angle is determined by the ratio of the focal length of the object glass to that of the eye glass (O. 510), and the increase of illumination is determined by the ratio of the area of the aperture of the object glass to that of the pupil, which areas are proportional to the squares of the diameters of the object glass and the pupil. The illumination will, therefore, vary in the ratio of the square of the aperture of the telescope.

To explain the effect of the telescope applied to stellar observation, let the sun or any similar object be imagined to be transferred to a gradually increased distance from the observer. The effect will be the gradual decrease of its visual diameter, and a corresponding decrease of the image on the retina. The brightness or intensity of illumination of that image will remain always the same (O. 364); and, consequently, the total quantity of light which falls upon it will be decreased in the exact ratio of its superficial magnitude,—that is, in the ratio of the square of its diameter. But this diameter is always proportional to the visual angle subtended at the eye by the object; and this angle decreases as the distance of the object increases. It follows, therefore, that the total quantity of light incident on the retina, from the same or similar objects at different distances, decreases as the square of the distance increases.

Now, let the distance of the sun from the observer be imagined to be increased until the visual angle becomes so small that no sensible impression of the form or magnitude of the object is produced. Let this distance be expressed by D'. The appearance of the sun would then be that of a mere luminous point, without apparent magnitude or form. It would in fact, therefore, have the same appearance as that of a star or planet. Vision would depend on the mere excitation of the retina by the quantity of light acting upon it, and not on the form or magnitude of the picture produced upon it. The first of the above-mentioned conditions of distinct vision would fail to be fulfilled, but the second would be still fulfilled. Light without form or magnitude would, therefore, be the sensible impression on the observer.

If we now imagine the sun to continue to be transferred to greater and greater distances, the image on the retina will be proportionally diminished in magnitude; but as its magnitude has already ceased to be sensible because of its minuteness, this decrease of magnitude will necessarily also be insensible. But the total quantity of light falling upon the retina will also be decreased, and this decrease will be in the ratio of the increase of the square of the distance. Now, since the apparent brightness of the luminous point to which the sun would be in this case reduced, must depend altogether on the total quantity of light falling on the retina, this brightness will be in the inverse ratio of the square of the distance.

Let L' be the total quantity of light falling on the retina, or the apparent brightness of the object at the distance D' at which it ceases to have a sensible disk, and let L be its apparent brightness, at any greater distance D. We shall then, according to what has just been explained, have

$$L : L' :: D'^2 : D^2;$$

and consequently,

$$L = L' \times \frac{D'^2}{D^2},$$

from which it appears again that L will decrease as D^2 increases.

By the continual increase of D, therefore, the apparent brightness of the luminous point to which the object has been reduced, would be continually diminished, and it would successively assume the appearance of stars of less and less magnitude, until at length the quantity of light falling on the retina would become so small that it would be insufficient to produce a sensible impression on the organ, and the object would cease to be seen. Let the distance at which this would take place be D''.

It appears, then, that in the gradations of the optical impression

produced by such a continually receding object, there are two limiting distances, the lesser D′ at which it ceases to have sensible magnitude but continues to be visible as a lucid point, and the greater D″ at which it ceases to be seen altogether; and that at intermediate distances D it appears as a lucid point of all degrees of brightness, less than that which it has at the distance D′.

If this reasoning be applied to different objects, it is evident that the distance D′ will vary with the real diameter of the object, and will be exactly proportional to it. The distance D″ for objects having the same real diameter, will vary with their intrinsic lustre, or the relative quantities of light which they emit from their visible hemispheres, and will be greater in the ratio of the square root of the absolute quantity of light emitted.

If a telescope be directed to a star at any distance D greater than D″, its magnifying power will be incapable, however great it may be, of augmenting the visual angle to such an extent as to render it greater than it would be, if the star were at the distance D′, at which the visual angle becomes so small as to be inappreciable by the eye. But in the same case, the power of the telescope to increase the quantity of light which enters the pupil, will produce effects which are not only very sensible, but which may be increased almost indefinitely, by augmenting the aperture of the telescope. In this way, although the magnifying power is altogether inefficacious so far as relates to the visual angle of the object, its power, so far as relates to the increase of light or increase of apparent brightness of the object, becomes of the greatest importance. Thus it is evident, that a telescope of a certain aperture directed to a star of the sixth magnitude, the light of which, according to the estimate of Sir J. Herschel, is about the 100th part of the light of such a star of the first magnitude as α Centauri, would render it equal in apparent brightness to the latter, and would, therefore, have the effect of bringing it so much nearer to the observer, as the distance of an average star of the first magnitude is less than an average star of the sixth magnitude. But since the apparent brightness decreases as the square of the distance increases, it follows that a star of the sixth magnitude, being 100 times less bright than a star of the first magnitude, will be 10 times more distant. The telescope, therefore, in this case, would have the effect of bringing the star 10 times nearer to the observer.

By knowing the relation of the aperture of the telescope, whether it be a refractor or reflector, to the magnitude of the pupil, and the proportion of light lost in being transmitted to the eye by the lenses or specula of the instrument, it is easy to calculate the ratio in which it will increase the apparent brightness of a star, and this ratio being known, it will be easy to ascertain how much

more distant such a star is, than one which to the naked eye would have the same apparent brightness.

677. **Space-penetrating power.**—The reflecting telescope used by Sir William Herschel, in some of his principal stellar researches, had an aperture of eighteen inches, and twenty feet focal length with a magnifying power of 180. The space-penetrating power of this instrument was found to be seventy-five, the meaning of which is, that when directed to a star of any given brightness, it would augment its brightness so as to make it appear the same as it would be if at seventy-five times less distance, or what is the same, that a star which to the naked eye would appear of the same brightness as that star does when seen in the telescope, would require to be removed to seventy-five times the actual distance, so that when seen through the telescope it would have the brightness it has when seen with the naked eye. Thus a star of the sixth magnitude, if removed to seventy-five times the actual distance, would appear in such an instrument still as a star of the sixth magnitude would to the naked eye, and if we assume with Sir John Herschel, that a star of the sixth magnitude has a hundred times less light than α Centauri, and is therefore at ten times a greater distance, it will follow that α Centauri would require to be removed to seven hundred and fifty times its actual distance, so that when viewed through such a telescope it would be seen as a star of the sixth magnitude to the naked eye.

If, then, it be assumed, as it may fairly be, that among the innumerable stars which are beyond the range of unaided vision, and brought into view by the telescope, a large proportion must have the same magnitude and intrinsic brightness as the average stars of the first magnitude, it will follow that these must be at distances 750 times greater than the distance of an average star of the first magnitude, such as α Centauri. The distance of this star is such, that light would require 3·54325 years to come from it to the earth. It would, therefore, follow that the distance of the telescopic stars just referred to, must be such, that light would take to come from them to the earth 2657·4375 years. The distance of such stars, taking the earth's distance from the sun as the unit, appears therefore to be about one hundred and seventy million times the distance of the sun, and since that distance expressed in round numbers is one hundred millions of miles, it will follow that the distance of such a star is seventeen thousand billions of miles.

We arrive, therefore, at the somewhat astonishing conclusion that the distance of these objects, the existence of which the telescope alone has disclosed to us, must be such, that light, moving at the rate of 184,000 miles per second, takes upwards of 2600 years

to come from them to us, and consequently that the objects we now see are not those which now exist, but those which did exist 2600 years ago; and it is within the scope of physical possibility that they may have changed their conditions of existence, and consequently of appearance, or even have ceased to exist altogether, more than 2000 years ago, although we actually see them at this moment.

This incidentally shows that the actual perception of a visible object is no conclusive evidence of its present existence. It is only a proof of its existence at some anterior period.

678. **Telescopic stars.**— It appears, therefore, that there are numerous orders of stars, which by reason of their remoteness are invisible to the naked eye, but which are rendered visible by the telescope; and these stars are, like those visible to the naked eye, of an infinite variety of degrees of magnitude and brightness, and have accordingly been classed by astronomers, according to an order of magnitude in numerical continuation of that which has been somewhat indefinitely or arbitrarily adopted for the visible stars. Thus, supposing that the last order of stars visible without telescopic aid is the seventh, the first order disclosed by the telescope will be the eighth, and from these the telescopic stars, decreasing in magnitude, have been denominated the ninth, tenth, eleventh, &c. to the sixteenth or seventeenth magnitude, the last being the smallest stars which are capable of being rendered distinctly visible by the most powerful telescope.

679. **Stellar nomenclature.**—Besides the classification of stars according to their estimated degrees of magnitude or brightness, they are also designated according to their distribution over the imaginary surface of the celestial sphere. Whether the apparent grouping of these objects depends on any physical relation existing between the members composing each group, or is the result of the fortuitous relation of the visual lines directed to them, the principal collections of the more conspicuous stars thus placed in near apparent vicinity, have been recognised from the most remote antiquity, and such groups have been commonly denominated CONSTELLATIONS.

Although in certain cases, it is probable that some physical relation may exist between the more close neighbours in these constellations, it is certain that the apparent juxta-position and relative arrangement of the component stars generally is altogether fortuitous. Imagination, has, however, connected them together, and invested such constellations with the forms of mythological figures, animals, such as bears, dogs, lions, goats, serpents, and so on, from which they severally take their names. Unreasonable as such a system must be allowed to be, it is not

without its use as a means of reference and an artificial aid to the memory. That a better system of signs and symbols might have been devised for these purposes, may be admitted; but when it is considered that the names and forms of the most conspicuous constellations have had their origin in remote antiquity — that they were handed down from the Chaldeans to the Egyptians, from the Egyptians to the Greeks, and from these to the moderns — that they are referred to in the works of every past astronomer, and registered in the memory of every living observer — that they are associated with the productions of art, and supply illustrations to the orator and the poet — it will be readily admitted that, even though a general change of the stellar nomenclature and symbols were practicable, it would neither be advantageous nor advisable.

As an example of a constellation, the group of seven conspicuous stars, arranged nearly in the form of a note of interrogation, visible in the northern part of the firmament, and in these latitudes always above the horizon, may be referred to. This constellation is called Ursa major (the Great Bear). The seven stars are only the more conspicuous of those which compose the constellation, the entire number being eighty-seven, most of them, however, being telescopic; of the seven chief stars one only is of the first magnitude, three are of the second, and three of the third.

The seven principal stars of this constellation being all less than forty degrees from the north pole, will be always above the horizon in latitudes greater than forty degrees. Hence it is that this constellation is so familiarly known. They may serve as standards or *moduli* by which the astronomical amateur may estimate the orders of magnitudes of the stars generally. It is in the quarter of the heavens opposite to that in which the sun is in the month of March, and is therefore visible at midnight near the meridian above the pole at that season. In the month of September it is visible at midnight below the pole.

The stars which compose a constellation are designated usually by the letters of the Greek alphabet, the first letters being generally assigned to the most conspicuous. The order of the letters, however, does not always follow strictly the order of magnitudes. When the stars are not designated by letters, they are distinguished by numbers, and this is mostly the case with the smaller stars.

It is usual to express the constellations by their Latin names, and to designate the individual stars by the letter or number and the constellation, as α *Lyræ*, β *Ursæ majoris*, 61 *Ophiuchi*, 24 *Comæ*, &c.

In the cases of some of the more conspicuous stars, such as have been objects of observation in remote ages, they are also frequently distinguished by proper names. Thus, α *Canis majoris* is more

commonly called *Sirius*, and sometimes the *Dog-star*, and is known as the most resplendent of the fixed stars. In like manner, α *Piscis Australis* is always called *Fomalhaut*, α and β *Geminorum* are called *Castor* and *Pollux*, β *Orionis* is known as *Rigel*, α *Tauri* as *Aldebaran*, α *Virginis* as *Spica*, α *Boötis* as *Arcturus*, and so on.

The practical usefulness of the imaginary figures which give names to the constellations, will thus be understood. If we desire to express the position of the star η *Ursæ majoris*, for example, we say that it is at the *tip of the tail* of the Great Bear. We indicate, in like manner, the place of the three remarkable stars, δ, ϵ, and ζ Orionis, by saying that they form the belt of Orion, and another, Rigel, by saying that it is on his foot. The star Sirius is on the nose of Canis major, and the bright star β on his left fore-foot.

680. **Use of pointers.**—Those who desire to obtain an acquaintance with the stars, will find much advantage in practising the method of *pointers*, by which the position of conspicuous stars with which the observer is well acquainted, is used to ascertain the places of others which are less known and less easily identified. This method consists in assigning two conspicuous stars so placed, that a straight line imagined to be drawn between them, and continued if necessary in the same direction, will pass through or near the star whose position it is desired to ascertain.

The most useful example of the application of this method, is the case of the pole star, which is α *Ursæ minoris*, a star of the third magnitude. Let the observer direct his eye to the two conspicuous stars, α and β *Ursæ majoris*, and supposing a straight line drawn from β to α, let him carry his eye along that line beyond α to a distance about six times the space between α and β, he will arrive at the pole star.

681. **Use of star maps.**—To comprehend the preceding paragraphs, and profit by the instructions given in them, it will be necessary for the reader to have in his hands a set of star maps. The GUIDE TO THE STARS* will be found to be one of the most convenient works for this purpose. In the maps there given, will be found indications of the most useful applications of the method of pointing.

682. **Use of the celestial globe.**—A celestial globe may be defined to be a working model of the heavens. It is mounted like a common terrestrial globe. The visible hemisphere is bounded by the horizontal circle in which the globe rests. The brass circle at right angles to this, is the celestial meridian. The constellations, with outlines of the imaginary figures from which they take their names, are delineated upon it.

* Twelve Planispheres, forming a Guide to the Stars for every Night in the Year with an Introduction.— *Walton and Maberly, London.*

The globe will serve, not merely as an instrument of instruction, but will prove a ready and convenient aid to the amateur in astronomy, superseding the necessity of many calculations, which are often discouraging and repulsive, however simple and easy they may be to those who are accustomed to such inquiries. Most of the almanacs contain tables of the principal astronomical phenomena, of the places of the sun and moon, and of the principal planets, as well as the times when the most conspicuous stars are on the meridian after sunset. These data, together with a judicious use of the globe and a tolerable telescope, will enable any person to extend his acquaintance with astronomy, and even to become a useful contributor to the common stock of information, which is now so fast increasing by the zeal and ability of private observers in so many quarters of the globe.

To prepare the globe for use, let small marks (bits of paper gummed on will answer the purpose) be placed upon it, to indicate the positions of the sun, moon, and planets, at the time of observing the heavens. The place of the sun on the ecliptic is usually marked on the globe itself. If not, its right ascension (that is, its distance from the vernal equinoxial point, measured on the celestial equator), and its declination (that is, its distance north or south of the equator), are given in the almanac, for every day. The moon's right ascension and declination are likewise given.

683. **To find the place of an object on the globe when its right ascension and declination are known.**—Find the point on the equator where the given right ascension is marked. Turn the globe on its axis till this point be brought under the meridian. Then count off an arc of the meridian (north or south of the equator, according as the declination is given) of a length equal to the given declination, and the point of the globe immediately under the point of the meridian thus found, will be the place of the object. By this rule, the position on the globe of any object of which the right ascension and declination are known, may be immediately found, and a corresponding mark put upon it.

To adjust the globe so as to use it as a guide to the position of objects on the heavens, and as a means of identifying the stars and learning their names, let the lower clamping-screw of the meridian be loosened, and let the north pole of the globe be elevated by moving the brass meridian until the arc of this meridian between the pole and the horizon be equal to the latitude of the place of observation. Let the clamping-screw be then tightened, so as to maintain the meridian in this position. Let the globe be then so placed that the brass meridian shall be directed due north and south, the pole being turned to the north. This being done, the globe will correspond with the heavens

so far as relates to the poles, the meridian, and the points of the horizon.

To ascertain the aspect of the firmament at any hour of the night, it is now only necessary to turn the globe upon its axis until the mark indicating the place of the sun shall be under the horizon in the same position as the sun itself actually is at the hour in question. To effect this, let the globe be turned until the mark indicating the position of the sun is brought under the meridian. Observe the hour marked on the point of the equator which is then under the meridian. Add to this hour the hour at which the observation is about to be taken, and turn the globe until the point of the equator on which is marked the hour resulting from this addition is brought under the meridian. The position of the globe will then correspond with that of the firmament. Every object on the one will correspond in its position with its representative mark or symbol on the other. If we imagine a line drawn from the centre of the globe through the mark upon its surface indicating any star, such a line, if continued outside the surface toward the heavens, would be directed to the star itself.

For example, suppose that when the mark of the sun is brought under the meridian, the hour $5^h\ 40^m$, is found to be on the equator at the meridian, and it is required to find the aspect of the heavens at half-past ten o'clock in the evening.

		H.	M.
To	-	5	40
Add	-	10	30
		16	10

Let the globe be turned until $16^h\ 10^m$ is brought under the meridian, and the aspect given by it will be that of the heavens.

CHAPTER XX.

PERIODIC, TEMPORARY, AND MULTIPLE STARS. — PROPER MOTION OF STARS. — MOTION OF THE SOLAR SYSTEM.

684. **Telescopic observations on individual stars.** — Besides bringing within the range of observation objects placed beyond the sphere which limits the play of natural vision, the telescope has greatly multiplied the number of objects visible within that sphere, by enabling us to see many rendered invisible by their minuteness, or confounded with others by their apparent proximity. Among the stars also which are visible to the naked eye, there are many, respecting which the telescope has disclosed

circumstances of the highest physical interest, by which they ha become more closely allied to our system, and by which it demonstrated that the same material laws which coerce the plane and give stability, uniformity, and harmony to their motions, a also in operation in the most remote regions of the universe. V shall first notice some of the most remarkable discoveries respecti individual stars, and shall afterwards explain those which indica the arrangement, dimensions, and form of the collective mass stars which compose the visible firmament, and the results of tho researches which the telescope has enabled astronomers to ma in regions of space still more remote.

I. PERIODIC STARS.

685. **Stars of variable lustre.** — The stars in general, as th are stationary in their apparent positions, are equally invariable their apparent magnitudes and brightness. To this, howev there are several remarkable exceptions. Stars have been o served, sufficiently numerous to be regarded as a distinct cla which exhibit periodical changes of appearance. Some under gradual and alternate increase and diminution of magnitud varying between determinate limits, and presenting these variatio in equal intervals of time. Some are observed to attain a certa maximum magnitude, from which they gradually and regular decline until they altogether disappear. After remaining for certain time invisible, they reappear and gradually increase t they attain their maximum splendour, and this succession changes is regularly and periodically repeated. Such objects a called *periodic stars.*

686. **Remarkable stars of this class in the constellatio of Cetus and Perseus.** — The most remarkable of this class the star called *Omikron*, in the neck of the Whale, which was fi observed by David Fabricius, on the 13th of August, 1596. Th star retains its greatest brightness for about fourteen days, bei then equal to a large star of the second magnitude. It th decreases continually for three months until it becomes invisib It remains invisible for five months, when it reappears, a increases gradually for three months until it recovers its maximu splendour. This is the general succession of its phases. I entire period is about 331 days. This period is not always t same, and the gradations of brightness through which it passes a said to be subject to variation. Hevelius states that, in the i terval between 1672 and 1676, it did not appear at all.

Some recent observations and researches of M. Argelande render it probable that the period of this star is subject to a vari tion which is itself periodical, the period being alternately au

mented and diminished to the extent of 25 days. The variations of the maximum lustre are also probably periodical.

The star called *Algol*, in the head of *Medusa*, in the constellation of *Perseus*, affords a striking example of the rapidity with which these periodical changes sometimes succeed each other. This star generally appears as one of the second magnitude; but an interval of seven hours occurs at the expiration of every sixty-two, during the first three hours and a half of which it gradually diminishes in brightness till it is reduced to a star of the fourth magnitude, and during the remainder of the interval it again gradually increases until it recovers its original magnitude. Thus, if we suppose it to have attained its maximum splendour at midnight on the first day of the month, its changes would be as follows: —

D. H. M.		D. H. M.	
0 0 0	to	2 14 0	It appears of second magnitude.
2 14 0	to	2 17 24	It decreases gradually to fourth magnitude.
2 17 24	to	2 20 48	It increases gradually to second magnitude.
2 20 48	to	5 10 48	It appears of second magnitude.
5 10 48	to	5 14 12	It decreases to fourth magnitude.
5 14 12	to	5 17 36	It increases to second magnitude.
&c.		&c.	&c.

This star presents an interesting example of its class, as it is constantly visible, and its period is so short that its succession of phases may be frequently and conveniently observed. It is situate near the foot of the constellation *Andromeda*, and lies a few degrees north-east of three stars of the fourth magnitude which form a triangle.

Goodricke, who discovered the periodic phenomena of *Algol* in 1782, explained these appearances by the supposition that some opaque body revolves round it, being thus periodically interposed between the earth and the star, so as to intercept a large portion of its light.

The more recent observations on this star indicate a decrease of its period, which proceeds with accelerated rapidity. Sir J. Herschel thinks that this decrease will attain a limit, and will be followed by an increase, so that the variation of the period will prove itself to be periodic.

The stars δ in *Cepheus* and β in *Lyra* are remarkable for the regular periodicity of their lustre. The former passes from its least to its greatest lustre in thirty-eight hours, and from its greatest to its least in ninety-one hours. The changes of lustre of the latter, according to the recent observations of M. Argelander, are very complicated and curious. Its entire period is 12 days 21 hrs.

53 min. 10 sec., and in that time it first increases in lustre, then decreases, then increases again, and then decreases, so that it has two maxima and two minima. At the two maxima its lustre is that of a star of the 3·4 magnitude, and at one of the minima its lustre is that of a star of the 4·3, and at the other that of a star of the 4·5 magnitude.

In this case also the period of the star is found to be periodically variable.

687. **Table of the periodic stars.** — Upwards of a hundred stars have been discovered to be periodically variable; in the following table will be found a list of those, whose limits of variability have been determined with some degree of accuracy.

Name of Star.	R. A.	N.P.D.	Change of Magnitude.		Period.	Discoverer of Variability.	Year of Discovery
	h. m.	° ′	from	to	days.		
T Piscium	0 25	76 14	9·5	11	245	Luther	1855
α Cassiopeiæ	0 33	34 14	2	2·5	79·1	Birt	1831
S Piscium	1 10	81 49	9	13		Hind	1851
R Piscium	1 23	87 51	7·5	11		Hind	1850
ο Ceti	2 12	93 37	2	under 12	331·3	Fabricius	1596
Algol	2 59	49 35	2·3	4	2·87	Goodricke	1782
λ Tauri	3 53	77 56	4	4·5	3·95	Baxendell	1848
R Tauri	4 21	80 9	8	under 13·5	330	Hind	1849
R Orionis	4 51	82 5	9	12·5		Hind	1848
ι Aurigæ	4 52	46 23	3·5	4·5		Heis	1846
α Orionis	5 48	82 37	1	1·5	196	Herschel	1836
ζ Geminorum	6 56	69 14	3·8	4·5	10·16	Schmidt	1847
R Geminorum	6 59	67 5	7	11	369·73	Hind	1848
R Canis Minoris	7 1	79 46	8	10		Argelander	1854
S Geminorum	7 35	66 13	9	under 13·5	294·07	Hind	1848
T Geminorum	7 41	65 55	9	under 13·5	288·62	Hind	1848
U Geminorum	7 47	67 38	9	under 13·5		Hind	1855
R Cancri	8 9	77 51	6	under 10	380	Schwerd	1829
S Cancri	8 36	70 28	8	10·5	9·48	Hind	1848
S Hydræ	8 46	86 24	8·5	13·5	256	Hind	1848
T Cancri	8 49	69 37	9·5	12		Hind	1850
T Hydræ	8 49	98 37	8·5	10·5		Hind	1851
R Leonis	9 40	77 55	5	10	312·57	Koch	1782
R Ursæ Majoris	10 35	20 29	7	13	301·90	Pogson	1853
η Argûs	10 40	148 56	1	4		Burchell	1827
R Hydræ	13 22	112 33	4	under 10	495	Maraldi	1704
S Virginis	13 26	96 28	5·5	11	380·11	Hind	1852
S Serpentis	15 15	75 11	8	10	367	Harding	1828
R Coronæ	15 43	61 25	6	12	323	Pigott	1795
R Serpentis	15 44	74 26	6·5	under 10	359	Harding	1826
S Ophiuchi	16 26	106 52	9·3	under 13·5	232	Pogson	1854
R Ophiuchi	17 0	105 54	8	under 13	301	Pogson	1853
α Herculis	17 8	75 27	3	3·5	66·33	W. Herschel	1795
R Scuti	18 40	95 50	5	9	71·75	Pigott	1795
β Lyræ	18 45	56 48	3·4	4·5	12·91	Goodricke	1784
13 Lyræ	18 51	46 14	4·3	4·6	48	Baxendell	1856
R Sagittarii	19 8	109 33	8·2	12·8	467	Pogson	1856
R Cygni	19 33	40 7	7·5	under 14	416·72	Pogson	1852
χ Cygni	19 45	57 27	5	under 11	406·06	Kirch	1687
η Aquilæ	19 45	89 21	3·6	4·4	7·18	Pigott	1784
U Capricorni	20 40	105 18	10·5	under 13	420	Pogson	1858
T Capricorni	21 14	105 45	9	14	274	Hind	
δ Cephei	22 24	32 18	3·7	4·8	5·37	Goodricke	1784
β Pegasi	22 57	62 41	2	2·5	41	Schmidt	1848
R Pegasi	23 0	80 14	8·5	under 13·5	350	Hind	1848
R Aquarii	23 37	106 3	7	10	388·5	Harding	1810
R Cassiopeiæ	23 51	39 23	6	14	434·81	Pogson	1853

The maximum and minimum extremes of lustre, with the periods when known, are given in the preceding table, the stars being arranged in the order of right ascension. The numbers are principally extracted from the lists of variable stars by Mr. Pogson. — (See Appendix, 815.)

In the case of many of these stars, the variations of lustre are subject to considerable irregularities. Thus χ Cygni was scarcely visible from 1698 for the interval of three years, even at the epochs when it ought to have had its greatest lustre. The extremes of lustre of R Scuti are also very variable and irregular. In general the variations of R Coronæ are so inconsiderable as to be scarcely perceivable, but they become sometimes suddenly so great that the star wholly disappears. The variations of α Orionis were very conspicuous from 1836 to 1840, and again in 1849, being much less so in the intermediate time.

688. **Hypotheses proposed to explain these phenomena.**— Several explanations have been proposed for these appearances.

1. Sir W. Herschel considered that the supposition of the existence of spots on the stars similar to the spots on the sun, combined with the rotation of the stars upon axes, similar to the rotation of the sun and planets, afforded so obvious and satisfactory an explanation of the phenomena, that no other need be sought.

2. Newton conjectured that the variation of brightness might be produced by comets falling into distant suns and causing temporary conflagrations. Waiving any other objection to this conjecture, it is put aside by its insufficiency to explain the periodicity of the phenomena.

3. Maupertius has suggested that some stars may have the form of thin flat disks, acquired either by extremely rapid rotation on an axis, or other physical cause. The ring of Saturn affords an example of this, within the limits of our own system, and the modern discoveries in nebular astronomy offer other examples of a like form. The axis of rotation of such a body might be subject to periodical change like the nutation of the earth's axis, so that the flat side of the luminous disk might be present more or less towards the earth at different times, and when the edge is so presented it might be too thin to be visible. Such a succession of phenomena is actually exhibited in the case of the rings of Saturn, though proceeding from different causes.

4. Mr. Dunn * has conjectured that a dense atmosphere surrounding the stars, in different parts more or less pervious to light, may explain the phenomena. This conjecture, otherwise vague, indefinite, and improbable, totally fails to explain the periodicity of the phenomena.

* *Philosophical Transactions*, vol. lii.

5. It has been suggested that the periodical obscuration or total disappearance of the star may arise from *transits* of the star by its attendant planets. The transits of Venus and Mercury are the basis of this conjecture.

The transits of none of the planets of the solar system, seen from the stars, could render the sun a periodic star. The magnitudes, even of the largest of them, are altogether insufficient for such an effect. To this objection it has been answered, that planets of vastly great comparative magnitude may revolve round other suns. But if the magnitude of a planet were sufficient to produce by its transit these considerable obscurations, it must be very little inferior to the magnitude of the sun itself, or at all events it must bear a very considerable proportion to the magnitude of the sun; in which case it may be objected that the predominance of attraction necessary to maintain the sun in the centre of its system could not be secured. To this objection it is answered, that although the planet may have a great comparative *magnitude*, it may have a very small comparative *density*, and the gravitating attraction depending on the actual mass of matter, the predominance of the solar mass may be rendered consistent with the great relative magnitude of the planet by supposing the density of the one vastly greater than that of the other. The density of the sun is much greater than the density of Saturn.

6. It has been suggested that there may be systems in which the central body is a planet attended by a lesser sun revolving round it as the moon revolves round the earth, and in that case the periodical obscuration of the sun may be produced by its passage once in each revolution behind the central planet.

Such are the various conjectures which have been proposed to explain the periodic stars; and as they are merely conjectures, scarcely deserving the name of hypotheses or theories, we shall leave them to be taken for what they are worth.

II. TEMPORARY STARS.

Phenomena in most respects similar to those just described, but exhibiting no recurrence, repetition, or periodicity, have been observed in many stars. Thus, stars have from time to time appeared in various parts of the firmament, have shone with extraordinary splendour for a limited time, and have then disappeared and have never again been observed.

689. **Temporary stars seen in ancient times.**—The first star of this class which has been recorded, is one observed by *Hipparchus*, 125 B.C., the disappearance of which is said to have led that astronomer to make his celebrated catalogue of the fixed stars; a work

which has proved in modern times of great value and interest. In the 389th year of our era, a star blazed forth near α *Aquilæ*, which shone for three weeks, appearing as splendid as the planet Venus, after which it disappeared and has never since been seen. In the years 945, 1264, and 1572, brilliant stars appeared between the constellations of *Cepheus* and *Cassiopeia*. The accounts of the positions of these objects are obscure and uncertain, but the intervals between the epochs of their appearances being nearly equal, it has been conjectured that they were successive returns of the same periodic star, the period of which is about 300 years, or possibly half that interval.

The appearance of the star of 1572 was very remarkable, and having been witnessed by the most eminent astronomers of that day, the account of it may be considered to be well entitled to confidence. *Tycho Brahe*, happening to be on his return on the evening of the 11th of November from his laboratory to his dwelling-house, found a crowd of peasants gazing at a star which he was sure did not exist half an hour before. This was the temporary star of 1572, which was then as bright as Sirius, and continued to increase in splendour until it surpassed Jupiter when that planet is most brilliant, and finally it attained such a lustre that it was visible at mid-day. It began to diminish in December, and altogether disappeared in March, 1574.

On the 10th of October, 1604, a splendid star suddenly burst out in the constellation of *Serpentarius*, which was as bright as that of 1572. It continued visible till October, 1605, when it vanished.

690. **Temporary star observed by Mr. Hind.**—A star of the fifth magnitude, easily visible to the naked eye, was seen by Mr. Hind in the constellation of Ophiuchus, on the night of the 28th of April, 1848. From the perfect acquaintance of that observer with the region of the firmament in which he saw it, he was quite certain that, previous to the 5th of April, no star brighter than those of the ninth magnitude had been there, nor is there any star in the catalogues at all corresponding to that which he saw there on the 28th. This star continued to be observed at the Royal Observatory, Greenwich, until the year 1851. On the 17th of June, its magnitude was estimated about the fourteenth, being too faint for the usual meridional observation. Since this time it does not appear to have been again observed.

691. **Missing stars.**—To the class of temporary stars may be referred the cases of numerous stars which have disappeared from the firmament. On a careful examination of the heavens, and a comparison of the objects observed with former catalogues, and of catalogues ancient and modern with each other, many stars for-

merly known are now ascertained to be missing; and although, as Sir John Herschel observes, there is no doubt that in many instances these apparent losses have proceeded from mistaken entries, yet it is equally certain that in numerous cases there can have been no mistake in the observation or the entry, and that the star has really existed at a former epoch, and as certainly has since disappeared.

When we consider the vast length of many of the periods of astronomical phenomena, it is far from being improbable that these phenomena which seem to be occasional, accidental, and springing from the operation of no regular physical causes, such as those indicated by the class of variable stars first considered, may after all be periodic stars of the same kind, whose appearances and disappearances are brought about by similar causes. All that can be certainly known respecting them is, that they have appeared or disappeared once in that brief period of time within which astronomical observations have been made and recorded. If they be periodic stars, the length of whose period exceeds that interval, their changes could only have been once exhibited to us, and after ages have rolled away, and time has converted the future into the past, astronomers may witness the next occurrence of their phases, and discover that to be regular, harmonious, and periodic, which appears to us accidental, occasional, and anomalous.

III. DOUBLE STARS.

When the stars are examined individually by telescopes of a certain power, it is found that many which to the naked eye appear to be single stars are in reality two stars placed so close together that they appear as one. These are called *double stars.*

692. **Researches of Sir W. and Sir J. Herschel.** — A very limited number of these objects had been discovered before the telescope had received the vast accession of power which was given to it by the labour and genius of Sir William Herschel. That astronomer observed and catalogued 500 double stars; and subsequent observers, among whom his son, Sir John Herschel, holds the foremost place, have augmented the number to 6000.

693. **Stars optically double.** — The close apparent juxtaposition of two stars on the firmament is a phenomenon which might be easily explained, and which could create no surprise. Such an appearance would be produced by the accidental circumstance of the lines of direction of the two stars as seen from the earth, forming a very small angle, in which case, although the two stars might in reality be as far removed from each other as any stars in the heavens, they would nevertheless *appear* close together.

The *fig.* 98, will render this easily understood. Let *a* and *b* be the two stars seen from *c*. The star *a* will be seen relatively to *b*, as if it were at *d*, and the two objects will seem to be in close juxta-

Fig. 98.

position; and if the angle under the lines *c a* and *c b* be less than the sum of the apparent semidiameters of the stars, they would actually appear to touch.

694. **This supposition not generally admissible.**—If such objects were few in number, this mode of explaining them might be admitted; and such may, in fact, be the cause of the phenomenon in some instances. The chances against such proximity of the lines of direction are however so great as to be utterly incompatible with the vast number of double stars that have been discovered, even were there not, as there is, other conclusive proof that this proximity and companionship is neither accidental nor merely apparent, but that the connection is real, and that the objects are united by a physical bond analogous to that which attaches the planets to the sun.

But apart from the proofs of real proximity which exist respecting many of the double stars, and which will presently be explained, it has been shown that the probability against mere optical juxtaposition such as that described above is almost infinite. Professor Struve has shown that, taking the number of stars whose existence has been ascertained by observation down to the 7th magnitude inclusive, and supposing them to be scattered fortuitously over the entire firmament, the chances against any two of them having a position so close to each other as 4″ would be 9570 to 1. But when this calculation was made, considerably more than 100 cases of such duple juxtaposition were ascertained to exist. The same astronomer also calculated that the chances against a third star falling within 32″ of the first two would be 173,524 to one; yet the firmament presents at least four such triple combinations.

Among the most striking examples of double stars may be mentioned the bright star *Castor*, which, when sufficiently magnified, is proved to consist of two stars between the third and fourth magnitudes, within five seconds of each other. There are many, however, which are separated by intervals less than one second;

such as ϵ *Arietis, Atlas Pleiadum,* γ *Coronæ,* η and ζ *Herculis,* and τ and λ *Ophiuchi.*

695. **Argument against mere optical double stars derived from their proper motion.**—Another argument against the supposition of mere fortuitous optical juxtaposition, unattended by any physical connection, is derived from a circumstance which will be fully explained hereafter. Certain stars have been ascertained to have a *proper motion,* that is, a motion exclusively belonging to each individual star, in which the stars around it do not participate. Now, some of the double stars have such a motion. If one individual of the pair were affected by a proper motion, in which the other does not participate, their separation at some subsequent epoch would become inevitable, since one would necessarily move away from the other. Now, no such separation has in any instance been witnessed. It follows, therefore, that the proper motion of one equally affects the other, and consequently, that their juxtaposition is real and not merely optical.

696. **Struve's classification of double stars.**—The systematic observation of double stars, and their reduction to a catalogue with individual descriptions, commenced by Sir W. Herschel, has been continued with great activity and success by Sir J. Herschel, Sir J. South, and Professor Struve, so that the number of these objects now known, as to character and position, amounts to several thousand, the individuals of each pair being less than 32″ asunder. They have been classed by Professor Struve according to their distances asunder, the first class being separated by a distance not exceeding 1″, the second between 1″ and 2″, the third between 2″ and 4″, the fourth between 4″ and 8″, the fifth between 8″ and 12″, the sixth between 12″ and 16″, the seventh between 16″ and 24″, and the eighth between 24″ and 32″.

697. **Selection of double stars.**—The double stars in the following Table have been selected by Sir J. Herschel from Struve's catalogue, as remarkable examples of each class well adapted for observations by amateurs, who may be disposed to try by them the efficiency of telescopes. (*See next page.*)

698. **Coloured double stars.**—One of the characters observed among the double stars is the frequent occurrence of stars of different colours found together. Sometimes these colours are complementary (O. 185); and when this occurs, it is possible that the fainter of the two may be a white star, which appears to have the colour complementary to that of the more brilliant, in consequence of a well-understood law of vision, by which the retina being highly excited by light of a particular colour is rendered insensible to less intense light of the same colour, so that

0″ to 1″.	1″ to 2″.	2″ to 4″.	4″ to 8″.	8″ to 12″.	12″ to 16″.	16″ to 24″.	24″ to 32″.
γ Coronæ	γ Circini.	α Piscium.	α Crucis.	β Orionis.	α Centauri.	α Canum Venat.	δ Herculis.
γ Centauri.	δ Cygni.	β Hydræ.	α Herculis.	γ Arietis.	β Cephei.	ε Normæ.	η Lyræ.
γ Lupi.	ε Chamæleontis.	γ Ceti.	α Geminorum.	γ Delphini.	β Scorpii.	ζ Piscium.	ι Cancri.
ι Arietis.	ζ Boötis.	γ Leonis.	δ Geminorum.	ζ Antliæ.	γ Volantis.	θ Serpentis.	κ Herculis.
ζ Herculis.	ι Cassiopeiæ.	γ Coronæ Aust.	ζ Coronæ.	η Cassiopeiæ.	η Lupi.	κ Coronæ Aust.	κ Cephei.
η Coronæ.	ι² Cancri.	γ Virginis.	θ Phœnicis.	θ Eridani.	ζ Ursæ maj.	χ Tauri.	ψ Draconis.
η Herculis.	ξ Ursæ maj.	δ Serpentis.	κ Cephei.	ι Orionis.	κ Boötis.	24 Comæ.	χ Cygni.
λ Cassiopeiæ.	π Aquilæ.	ε Boötis.	λ Orionis.	f Eridani.	8 Monocerotis.	41 Draconis.	23 Orionis.
λ Ophiuchi.	σ Coronæ.	ε Draconis.	μ Cygni.	2 Canum Venat.	61 Cygni.	61 Ophiuchi.	
π Lupi.	2 Camelopardali.	ε Hydræ.	ξ Boötis.				
η Ophiuchi.	32 Orionis.	ζ Aquarii.	ξ Cephei.				
φ Draconis.	52 Orionis.	ζ Orionis.	π Boötis.				
φ Ursæ maj.		ι Leonis.	ε Capricorni.				
χ Aquilæ.		ι Trianguli.	υ Argûs.				
ω Leonis.		κ Leporis.	ω Aurigæ.				
Atlas Pleiadum		μ Draconis.	μ Eridani.				
4 Aquarii.		μ Canis Majoris.	70 Ophiuchi.				
42 Comæ.		ρ Herculis.	12 Eridani.				
52 Arietis.		σ Cassiopeiæ.	32 Eridani.				
66 Piscium.		44 Boötis.	95 Herculis.				

the complement of the whole light of the fainter star finds the retina more sensible than that part which is identical in colour with the brighter star, and the impression of the complementary colour accordingly prevails. In many cases, however, the difference of colour of the two stars is real.

When the colours are complementary, the more brilliant star is generally of a bright red or orange colour, the smaller appearing bluish or greenish. The double stars ι Cancri and γ Andromedæ are examples of this. According to Sir J. Herschel, insulated stars of a red colour, some almost blood-red, occur in many parts of the heavens; but no example has been met with of a decidedly green or blue star unassociated with a much brighter companion.

699. **Triple and other multiple stars.** — When telescopes of the greatest efficiency are directed upon some stars, which to more ordinary instruments appear only double, they prove to consist of three or more stars. In some cases one of the two companions only is double, so that the entire combination is triple. In others both are double, the whole being, therefore, a quadruple star. An example of this latter class is presented by the star ε Lyræ. Sometimes the third star is much smaller than the principal ones, for example, in the cases of ζ Cancri, ξ Scorpii, 11 Monocerotis, and 12 Lyncis. In others, as in θ Orionis, the four component stars are all conspicuous.

Fig. 99.

700. **Attempts to discover the stellar parallax by double stars.**—When the attention of astronomers was first attracted to double stars, it was thought they would afford a most promising means of determining the annual parallax, and thereby discovering the distance of the stars. If we suppose the two individuals composing a double star, being situate very nearly in the same direction as seen from the earth, to be at very different distances, it might be expected that their apparent relative position would vary at different seasons of the year, by reason of the change of position of the earth.

Let A and B, *fig.* 99, represent the two individuals composing a double star. Let C and D represent two positions of the earth in its annual orbit, separated by an interval of half a year, and placed therefore on opposite sides of the sun S. When viewed from C, the star B will be to the left of the star A; and when viewed from D, it will be to the right of it. During the intermediate six months the relative change of position would gradually be effected, and

the one star would thus appear either to revolve annually round the other, or would oscillate semi-annually from side to side of the other. The extent of its play compared with the diameter C D of the earth's orbit, would supply the data necessary to determine the proportion which the distance of the stars would bear to that diameter.

The great problem of the stellar parallax seemed thus to be reduced to the measurement of the small interval between the individuals of double stars; and it happened fortunately, that the micrometers used in astronomical instruments were capable of measuring these minute angles with much greater relative accuracy than could be attained in the observations on greater angular distances. To these advantages were added the absence of all possible errors arising from refraction, errors incidental to the graduation of instruments, from uncertainty of levels and plumb-lines, from all estimations of aberration and precession; in a word, from all effects which, equally affecting both the individual stars observed, could not interfere with the results of the observations, whatever they might be.

701. **Observations of Sir W. Herschel.**—These considerations raised great hopes among astronomers, that the means were in their hands to resolve finally the great problem of the stellar parallax, and Sir William Herschel accordingly engaged, with all his characteristic ardour and sagacity, in an extensive series of observations on the numerous double stars, for the original discovery of which science was already so deeply indebted to his labours. He had not, however, proceeded far in his researches, when phenomena unfolded themselves before him, indicating a discovery of a much higher order and interest than that of the parallax which he sought. He found that the relative position of the individuals of many of the double stars which he examined were subject to a change, but that the period of this change had no relation to the period of the earth's motion. It is evident that whatever appearances can proceed from the earth's annual motion, must be not only periodic and regular, but must pass annually through the same series of phases, always showing the same phase on each return of the same epoch of the sidereal year. In the changes of position which Sir William Herschel observed in the double stars, no such series of phases presented themselves. Periods, it is true, were soon developed; but these periods were regulated by intervals which neither agreed with each other nor with the earth's annual motion.

702. **His discovery of binary stars.**—Some other explanation of the phenomena must, therefore, be sought for; and the illustrious observer soon arrived at the conclusion, that these apparent changes

of position were due to real motions in the stars themselves; that these stars, in fact, moved in proper orbits in the same manner as the planets moved around the sun. The slowness of the succession of changes which were observed, rendered it necessary to watch their progress for a long period of time before their motions could be certainly or accurately known; and accordingly, although these researches were commenced in 1778, it was not until the year 1803 that the observer had collected data sufficient to justify any positive conclusion respecting their orbital motions. In that and the following year, Sir William Herschel announced to the Royal Society, in two memorable papers read before that body, that there exist sidereal systems consisting of two stars revolving about each other in regular orbits, and constituting what he called *binary stars*, to distinguish them from double stars, generally so called, in which no such periodic change of position is discoverable. Both the individuals of a binary star are at the same distance from the eye in the same sense in which the planet Uranus and its attendant satellites are said to be at the same distance.

More recent observation has fully confirmed these remarkable discoveries. In 1841, Mädler published a catalogue of upwards of 100 stars of this class, and every year augments their number. These stars require the best telescopes for their observation, being generally so close as to render the use of very high magnifying powers indispensable.

703. **Extension of the law of gravitation to the stars.**—The moment the revolution of one star round another was ascertained, the idea of the possible extension of the great principle of gravitation to these remote regions of the universe naturally suggested itself. Newton has proved in his *Principia*, that if a body revolve in an ellipse by an attractive force directed to the focus, that force will vary according to the law which characterises gravitation. Thus an elliptical orbit became a *test* of the presence and sway of the law of gravitation. If, then, it could be ascertained that the orbits of the double stars were ellipses, we should at once arrive at the fact that the law of which the discovery conferred such celebrity on the name of Newton, is not confined to the solar system, but prevails throughout the universe.

704. **Orbit of star around star elliptic.**— The first distinct system of calculation by which the true elliptic elements of the orbit of a binary star were ascertained, was supplied in 1830, by M. Savary, who showed that the motion of one of the most remarkable of these stars (ξ *Ursæ majoris*) indicated an elliptic orbit described in 58¼ years. Professor Encke, by another process, arrived at the fact that the star 70 *Ophiuchi* moved in an ellipse with a period of 74 years. Several other orbits were ascertained

and computed by Sir John Herschel, MM. Mädler, Hind, Smyth, and others.

705. **Remarkable case of γ Virginis.**— The most remarkable of these, according to Sir John Herschel, is *γ Virginis;* not only on account of the length of its period, but by reason also of the great diminution of apparent distance and rapid increase of angular motion about each other, of the individuals composing it. It is a bright star of the fourth magnitude, and its component stars are almost exactly equal. It has been known to consist of two stars since the beginning of the eighteenth century, their distance being then between six and seven seconds; so that any tolerably good telescope would resolve it. Since that time they have been in conjunction, so that no telescope that was not of very superior quality was competent to show them otherwise than as a single star somewhat lengthened in one direction. At the present time the stars have passed each other, their angular distance being about four seconds. It fortunately happens that Bradley, in 1718, noticed and recorded, in the margin of one of his observation-books, the apparent direction of their line of junction as being parallel to that of two remarkable stars α and δ of the same constellation, as seen by the naked eye. They are entered also as distinct stars in Mayer's catalogue; and this affords also another means of recovering their relative situation at the date of his observations, which were made about the year 1756. Without particularising individual measurements, which will be found in their proper repositories, it will suffice to remark, that their whole series is represented by an ellipse.

706. **Singular phenomena produced by one solar system thus revolving round another.** — To understand the curious effects which must attend the case of a lesser sun with its attendant planets revolving round a greater, let the larger sun, *fig.* 100, with its planets be represented as S, in the focus of an ellipse, in which the lesser sun accompanied by *its* planets moves. At A this latter sun is in its perihelion, and nearest to the greater sun S. Moving in its periodical course to B, it is at its mean distance from the sun S. At D it is at aphelion, or its most distant point, and finally returns through C to its perihelion A. The sun S, because of its vast distance from the system A, would appear to the inhabitants of the planets of the system A much smaller than their proper sun; but, on the other hand, this effect of distance would be to a certain extent compensated by its greatly superior magnitude; for analogy justifies the inference that the sun S is greater than the sun A in a proportion equal to that of the magnitude of our sun to one of the planets. The inhabitants of the planets of the system A will then behold the spectacle of *two suns* in their

firmament. The annual motion of one of these suns will be determined by the motion of the planet itself in its orbit, but that of the other and more distant sun will be determined by the period of the lesser sun around the greater in the orbit A B D C. The rotation of the planets on their axes will produce two days of equal length, but not commencing or ending simultaneously. There will be in general *two sunrises* and *two sunsets!* When a planet is situate in the part of its orbit between the two suns, there will be no night. The two suns will then be placed exactly as our sun and moon are placed when the moon is full. When the one sun sets, the other will rise; and when the one rises, the other will set. There will be, therefore, continual day. On the other hand, when a planet is at such a part of its orbit that both suns lie in nearly the same direction as seen from it, both suns will rise and both will set together. There will then be the ordinary alternation of day and night as on the earth, but the day will have more than the usual splendour, being enlightened by two suns.

Fig. 100.

In all intermediate seasons the two suns will rise and set at different times. During a part of the day both will be seen at once in the heavens, occupying different places, and reaching the meridian at different times. There will be *two noons.* In the morning for some time, more or less, according to the season of the year, one sun only will be apparent, and in like manner, in the evening, the sun which first rose will be the first to set, leaving the dominion of the heavens to its splendid companion.

The diurnal and annual phenomena incidental to the planets attending the central sun S will not be materially different, except that to them the two suns will have extremely different magni-

tudes, and will afford proportionally different degrees of light. The lesser sun will appear much smaller, both on account of its really inferior magnitude and its vastly greater distance. The two days, therefore, when they occur, will be of very different splendour, one being probably as much brighter than the other as the light of noonday is to that of full moonlight, or to that of the morning or evening twilight.

But these singular vicissitudes of light will become still more striking when the two suns diffuse light of different colours. Let us examine the very common case of the combination of a *crimson* with a *blue* sun. In general, they will rise at different times. When the blue rises, it will for a time preside alone in the heavens, diffusing a blue morning. Its crimson companion, however, soon appearing, the lights of both being blended, a white day will follow. As evening approaches, and the two orbs descend toward the western horizon, the blue sun will first set, leaving the crimson one alone in the heavens. Thus a ruddy evening closes this curious succession of varying lights. As the year rolls on, these changes will be varied in every conceivable manner. At those seasons when the suns are on opposite sides of a planet, crimson and blue days will alternate, without any intervening night; and at the intermediate epochs all the various intervals of rising and setting of the two suns will be exhibited.

707. **Magnitudes of the stellar orbits.** — It is evident that in any case in which the parallax of a binary star, and consequently its distance from our system, has been or may be discovered, the magnitude of the orbit of one described round the other, can be determined with a precision and certainty proportional to those with which the parallax is known. For, in that case, the linear value of $1''$ at the star will be found by dividing the earth's distance from the sun by the parallax expressed in seconds.

The binary stars 61 *Cygni* and *α Centauri* supply examples of the application of this principle. The parallax of these stars has been ascertained (171). That of 61 Cygni is 0·348, and the semi-axis of the elliptic orbit of one star round the other is $15''\cdot5$. The semidiameter of the earth's orbit being D, therefore, the linear value of $1''$ at the star is $\frac{\text{D}}{0\cdot348}$, and the semi-axis a of the stellar orbit is

$$a = \text{D} \times \frac{15\cdot5}{0\cdot348} = 44\cdot54\ \text{D}.$$

It appears, therefore, that the semi-axis of the orbit is greater than that of Neptune's orbit in the ratio of 3 to 2.

The angle subtended by the semi-axis of the elliptic orbit

of α Centauri is not so certainly known, but is taken to be about 12″. The parallax of this star being 0″·976, we should then have

$$a = \text{D} \times \frac{12}{0·976} = 12·30\ \text{D}.$$

The semi-axis of the stellar orbit would, therefore, be rather more than one-quarter greater than that of the orbit of Saturn.

IV. PROPER MOTION OF THE STARS.

708. **The stars not absolutely fixed.** — In common parlance the stars are said to be *fixed*. They have received this epithet to distinguish them from the planets, the sun, and the moon, all of which constantly undergo changes of apparent position on the surface of the heavens. The stars, on the contrary, so far as the powers of the eye unaided by art can discover, never change their relative position in the firmament, which seems to be carried round us by the diurnal motion of the sphere, just as if the stars were attached to it, and merely shared in its apparent motion.

But the stars, though subject to no motion perceptible to the naked eye, are not absolutely fixed. When the place of a star on the heavens is exactly observed by means of good astronomical instruments, it is found to be subject to a change from month to month and from year to year, small indeed, but still easily observed and certainly ascertained.

709. **The sun not a fixed centre.** — It has been demonstrated by Laplace, that a system of bodies, such as the solar system, placed in space and submitted to no other continued force except the reciprocal attractions of the bodies which compose it, must either have its common centre of gravity stationary or in a state of uniform rectilinear motion.

710. **Effect of the sun's supposed motion on the apparent places of the stars.** — The chances against the conditions which would render the sun stationary, compared with those which would give it a motion in *some* direction with *some* velocity, are so numerous that we may pronounce it to be morally certain that our system is in motion in some determinate direction through the universe. Now, if we suppose the sun attended by the planets to be thus moved through space in any direction, an observer placed on the earth would see the effects of such a motion, as a spectator in a steamboat moving on a river would perceive his progressive motion on the stream by an apparent motion of the banks in a contrary direction. The observer on the earth would, therefore, detect such a motion of the solar system through space

by the apparent motion in the contrary direction with which the stars would be affected.

Such a motion of the solar system would affect different stars differently. All would, it is true, appear to be affected by a contrary motion, but all would not be equally affected. The nearest would appear to have the most perceptible motion, the more remote would be affected in a less degree, and some might, from their extreme distance, be so slightly affected as not to exhibit any apparent change of place, even when examined with the most delicate instruments. To whatever degree each star might be affected, all the changes of position would, however, apparently take place in the same direction.

The apparent effects would also be exhibited in another manner. The stars in that region of the universe toward which the motion of the system is directed, would appear to recede from each other. The spaces which separate them would seem to be gradually augmented, while, on the contrary, the stars in the opposite quarter would seem to be crowded more closely together, the distances between star and star being gradually diminished. This will be more clearly comprehended by *fig.* 101.

Let the line S S′ represent the direction of the motion of the system, and let S and S′ represent its positions at any two epochs.

Fig. 101.

At S, the stars A B C would be separated by intervals measured by the angles A S B, and B S C, while at S′ they would appear separated by the lesser angles A S′ B, and B S′ C. Seen from S′, the stars A B C would seem to be closer together than they were when seen from S. For like reasons the stars *a b c*, towards which the system is here supposed to move, would seem to be closer together when seen from S, than when seen from S′. Thus, in the quarter of the heavens towards which the system is moving, the stars might be expected to separate gradually, while in the opposite quarter they would become more condensed. In all the intermediate parts of the heavens they would be affected by a motion contrary to that of the solar system. Such in general would be the effects of a progressive motion of our system.

711. **Motion of the sun inferred from the proper motion of the stars.**—Although no general effect of this kind has been manifested in any conspicuous manner among the fixed stars, many of these objects have been found, in long periods of time, to have shifted their position in a very sensible degree. Thus, for example, the three stars, Sirius, Arcturus, and Aldebaran, have undergone, since the time of Hipparchus (130 B.C.), a change of position southwards, amounting to considerably more than half a degree. The double star 61 Cygni has, in half a century, moved through nearly $4'\cdot5$, the two stars composing it being carried along in parallel lines with common velocity. The stars ϵ Indi and μ Cassiopeiæ move at the rate of $7''\cdot74$ and $3''\cdot74$ annually.

Various attempts have been made to render these and other like changes of apparent position of the fixed stars compatible with some assumed motion of the sun. Sir W. Herschel, in 1783, reasoning upon the proper motions which had then been observed, arrived at the conclusion, that such appearances might be explained by supposing that the sun has a motion directed to a point near the star λ Herculis. About the same time, M. Prevost came to a like conclusion, assigning, however, the direction of the supposed motion to a point differing by 27° from that indicated by Sir W. Herschel.

Since that epoch the proper motions of the stars have been more extensively and accurately observed, and calculations of the motion of the sun which they indicate, have been made by several astronomers. The following points have been assigned as the direction of the solar motion in 1790:—

R. A.	N. P. D.	
260° 34′	63° 43′	Sir W. Herschel.
256 25	51 23	Argelander.
255 10	51 26	Ditto.
261 11	59 2	Ditto.
252 53	75 34	Luhndahl.
261 22	52 24	Otto Struve.
261 29	65 16	Airy.
263 44	65 0	Airy and Dunkin.

The first estimate of Argelander was made from the proper motions of 21 stars, each of which has an annual motion greater than $1''$; the second from 50 stars having annual proper motions between $1''$ and $0''\cdot5$, and the third from those of 319 stars having motions between $0''\cdot5$ and $0''\cdot1$. The estimate of M. Luhndahl is based on the motions of 147 stars, that of M. Struve on 392 stars, that of Mr. Airy on 113 stars, and that of MM. Airy and Dunkin on 1167 stars. (See Appendix, 812.)

The mean of all these estimates is a point whose right ascension is 259° 6′, and north polar distance 60° 29′, which it will be

seen differs very little from the point originally assigned by Sir W. Herschel.

The preceding calculations being based generally on observations of stars in the northern hemisphere, it was obviously desirable that similar estimates should be made from the observed proper motions of southern stars. Mr. Galloway undertook and executed these calculations; and found that the southern stars gave the direction of the solar motion for 1790, to be towards a point whose right ascension is 260° 1′, and north polar distance 55° 37′.

No doubt, therefore, can remain that the proper motion of the stars is produced by a real motion of the solar system, and that the direction of this motion in 1790 was towards a point of space which, seen from the then position of the system, had the right ascension of about 260°, and the north polar distance of about 60°.

712. **Velocity of the solar motion.**—It follows from these calculations, that the average displacement of the stars requires that the motion of the sun should be such as that if its direction were at right angles to a visual ray, drawn from a star of the first magnitude of average distance, its apparent annual motion would be 0″·3392; and taking the average parallax of such a star at 0″·209, it follows, therefore, that the annual motion of the sun would be 148,500,000 miles, a velocity equal to something more than the fourth of the earth's orbital motion.

713. **The probable centre of solar motion.**—The motion of the sun, which has been computed in what precedes, is that which it had at a particular epoch. No account is taken of the possible or probable changes of direction of such motion. To suppose that the solar system should move continuously in one and the same direction, would be equivalent to the supposition that no body or collection of bodies in the universe would exercise any attraction upon it. It is obviously more consistent with probability and analogy, that the motion of the system is *orbital*, that is to say, that it revolves round some remote centre of attraction, and that the direction of its motion must continually change, although such change, owing to the great magnitude of its orbit, and the relative slowness of its motion, be so very slow as to be quite imperceptible within even the longest interval over which astronomical records extend.

Attempts have, nevertheless, been made to determine the centre of the solar motion; and Dr. Mädler has thrown out a surmise that it lies at a point in or near the small constellation of the Pleiades.

This and like speculations must, however, be regarded as conjectural for the present.

CHAPTER XXI.

THE FORM AND DIMENSIONS OF THE MASS OF STARS WHICH COMPOSE THE VISIBLE FIRMAMENT.

714. **Distribution of stars on the firmament.** — The aspect of the firmament might, at first, impress the mind of an observer with the idea that the numerous stars scattered over it are destitute of any law or regularity of arrangement, and that their distribution is like the fortuitous position which objects casually flung upon such a surface might be imagined to assume. If, however, the different regions of the heavens be more carefully examined and compared, this first impression will be corrected, and it will, on the contrary, be found that the distribution of the stars over the surface of the celestial sphere follows a distinct and well-defined law; that their density, or the number of them which is found in a given space of the heavens, varies regularly, increasing continually in certain directions, and decreasing in others.

Sir W. Herschel submitted the heavens, or at least that part of them which is observable in these latitudes, to a rigorous telescopic survey, counting the number of individual stars visible in the field of view of a telescope of given aperture, focal length, and magnifying power, when directed to different parts of the firmament. The result of this survey proved that, around two points of the celestial sphere diametrically opposed to each other, the stars are more thinly scattered than elsewhere; that departing from these points in any direction, the number of stars included in the field of view of the same telescope increases first slowly, but at greater distances more rapidly; that this increase continues until the telescope receives a direction at right angles to the diameter which joins the two opposite points where the distribution is the least in number; and that in this direction the stars are so closely crowded together that it becomes, in some cases, impracticable to count them.

715. **Galactic circle and poles.** — The two opposite points of the celestial sphere, around which the stars are observed to be more thinly scattered than in other directions, have been called the GALACTIC POLES; and the great circle at right angles to the diameter joining these points, has been denominated the GALACTIC CIRCLE.

This circle intersects the celestial equator at two points, situate 10° east of the equinoxial points, and is inclined to the equator at an angle of 63°, and therefore to the ecliptic at an angle of 40°.

In referring to and explaining the distribution of the stars over the celestial sphere, it will be convenient to refer them to this circle and its poles, as, for other purposes, they have been referred to the equator and its poles. We shall, therefore, express the distance of different points of the firmament from the galactic circle, in either hemisphere, by the terms north or south GALACTIC LATITUDE.

716. **Variation of the stellar density in relation to this circle.** — The elaborate series of stellar observations in the northern hemisphere made during a great part of his life by Sir W. Herschel, and subsequently extended and continued in the southern hemisphere by Sir J. Herschel, has supplied data by which the law of the distribution of the stars, according to their galactic latitude, has been ascertained at least with a near approximation.

The great celestial survey executed by these eminent observers was conducted upon the principle explained above. The telescope used for the purpose had 18 inches aperture, 20 feet focal length, and a magnifying power of 180. It was directed indiscriminately to every point of the celestial sphere visible in the latitude of the places of observation.

It was by means of a vast number of distinct observations thus made, that the position of the galactic poles was ascertained. The density of the stars, measured by the number included in each "gauge" (as the field of view was called), was nearly the same for the same galactic latitude, and increased in proceeding from the galactic pole, very slowly at first, but with great rapidity when the galactic latitude was much diminished.

717. **Struve's analysis of Herschel's observations.** — An analysis of the observations of Sir W. Herschel, in the northern hemisphere, was made by Professor Struve, with the view of determining the mean density of the stars in successive zones of galactic latitude; and a like analysis has been made of the observations of Sir J. Herschel, in the southern hemisphere.

If we imagine the celestial sphere resolved into a succession of zones, each measuring 15° in breadth, and bounded by parallels to the galactic circle, the average number of stars included within a circle whose diameter is 15′, and whose magnitude, therefore, would be about the fourth part of that of the disk of the sun or moon, will be that which is given in the second column of the following Table.

off-shoots, conducted Sir W. Herschel to the conclusion, that the stars of our firmament, including those which the telescope renders visible, as well as those visible to the naked eye, instead of being scattered indifferently in all directions around the solar system through the depths of the universe, form a stratum of definite form and dimensions, of which the thickness bears a very small proportion to the length and breadth, and that the sun and solar system is placed within this stratum, very near its point of bifurcation, relatively to its breadth near its middle point, and relatively to its thickness (as would appear from the more recent observations) nearer to its northern than to its southern surface.

Let A C H D, *fig.* 102, represent a rough outline of a section of such a stratum, made by a plane passing through or near its centre. Let

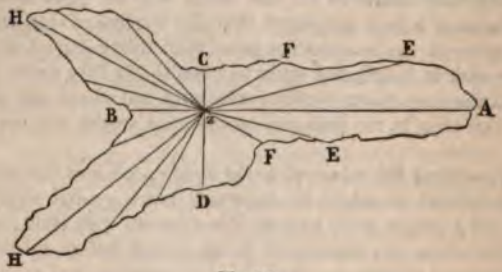

Fig. 102.

A B represent the intersection of this with the plane of the galactic circle, so that, Z being the place of the solar system, Z C will be the direction of the north, and Z D that of the south galactic pole. Let Z H represent the two branches which bifurcate from the chief stratum, at B. Now, if we imagine visual lines to be drawn from Z in all directions, it will be apparent that those Z C and Z D, which are directed to the galactic poles, pass through a thinner bed of stars than any of the others; and since Z is supposed to be nearer to the northern than to the southern side of the stratum, Z C will pass through a less thickness of stars than Z D. As the visual lines are inclined at greater and greater angles to Z A, their length rapidly decreases, as is evident by comparing Z A, Z E, and Z F, which explains the fact that while the stars are as thick as powder in the direction Z A, they become less so in the direction Z E, and still less in the direction Z F, until at the poles in the directions Z C and Z D, they become least dense.

On the other side, Z B being less than Z A, a part of the galactic circle is found at which the stars are more thinly scattered; but in two directions, Z H intermediate between Z B and the galactic poles, they again become nearly as dense as in the direction Z A.

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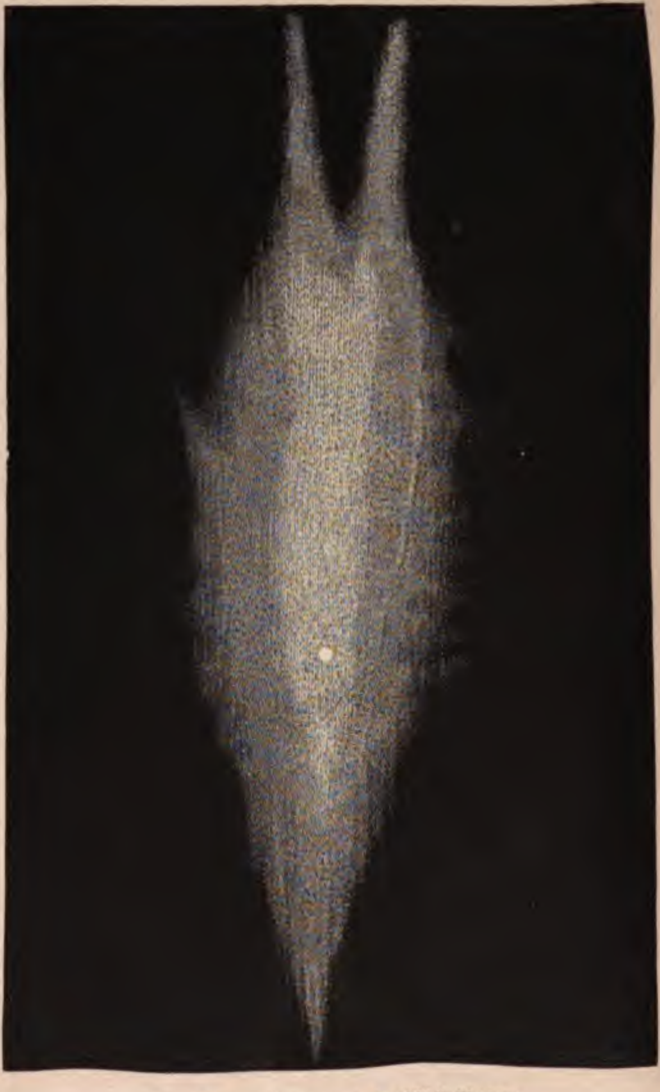
XXIX.



THE CLUSTER IN WHICH THE SUN IS PLACED.

This illustration must, however, be taken in a very general sense. No attempt is made to represent the various off-shoots and variations of length, breadth, and depth of the stratum measured from the position of the solar system within it, which have been indicated by the telescopic *soundings* of Sir W. Herschel and his illustrious son, whose wondrous labours have effected what promises in time, by the persevering researches of their successors, to become a complete analysis of this most marvellous mass of systems. Meanwhile it may be considered as demonstrated that it consists of myriads of stars clustered together:

> "A broad and ample road, whose dust is gold,
> And pavement stars, as stars to us appear,
> Seen in the galaxy, that Milky Way,
> Like to a circling zone powdered with stars."—MILTON.

The appearance which this mass of stars would present if viewed from a position directly above its general plane, and at a sufficient distance to allow its entire outline to be discerned, was represented by Sir William Herschel as resembling the starry stratum sketched in Plate XXIX.

He considered that it was probable that the *thickness* of this *bed of stars* was equal to about eighty times the distance of the nearest of the fixed stars from our system; and supposing our sun to be near the middle of this thickness, it would follow that the stars on its surface in a direction perpendicular to its general plane would be at the fortieth order of distance from us. The stars placed in the more remote edges of its *length* and *breadth* he estimated to be in some places at the nine-hundredth order of distance from us, so that its extreme length may be said to be in round numbers about 2000 times the distance of the nearest fixed stars from our system. Such a space light would take 20,000 years to move over, moving all that time at the rate of nearly 200,000 miles between every two ticks of a common clock!

CHAPTER XXII.

STELLAR CLUSTERS AND NEBULÆ.

721. **The stars which form the firmament a stellar cluster.—Analogy suggests the probable existence of others.**—It appears, then, that our sun is an individual star, forming only a single unit in a cluster or mass of many millions of other similar stars; that this cluster has limited dimensions, has ascertainable

727. **Forms apparent and real of the nebulæ.**—These objects exhibit forms much more various than those presented by the clusters. Some are circular, with more or less precision of outline. Some are elliptical, the oval outline having degrees of excentricity infinitely various, from one which scarcely differs from a circle, to one which is compressed into a form not sensibly different from a straight line. In short, the minor axis of the ellipses bears all proportions to the major axis, until it becomes a very small fraction of the latter.

To infer the real from the apparent forms of these objects with any certainty, there are no sufficient data. But in the cases in which the brightness increases rapidly towards the centre, which it very generally does, it may be probably conjectured that their forms are globular or spheroidal, for the reasons already explained in relation to the clusters, and this becomes the more probable when it is considered that these nebulæ are in fact clusters, the stars of which are reduced to a nebulous patch by distance.

Nevertheless, these nebulæ may be strata of stars, of which the thickness is small compared with their other dimensions; and supposing their real outline to be circular, they will appear elliptical if the plane of the stratum be inclined to the visual line, and more or less excentrically elliptical, according as the angle of inclination is more or less acute. In cases in which the brightness does not increase in a striking degree from the edges inwards, this form is more probable than the globular or the spheroidal.

Nebulæ may be conveniently classed according to their apparent form and structure; but whatever arrangement may be adopted, these objects exhibit such varieties, assume such capricious and irregular forms, and undergo such strange and unexpected changes of appearance according to the increasing power of the telescope with which they are viewed, that it will always be found that great numbers of them will remain unavoidably unclassified.

728. **Double nebulæ.**—Like individual stars, nebulæ are found to be combined in pairs too frequently to be compatible with the supposition that such combinations arise from the fortuitous results of the small obliquity of the visual rays, which causes mere optical juxtaposition.

These double nebulæ are generally circular in their apparent, and therefore probably globular in their real form. In some cases they are resolvable clusters.

That such pairs of clusters are physically connected does not admit of a reasonable doubt, and it is highly probable that, like the binary stars, they move round each other, or round a common centre of attraction, although the apparent motion attending such

revolution is rendered so slow by their immense distance that it can only be ascertained after the lapse of ages.

729. **Planetary nebulæ.**—This class of objects derive their name from their close resemblance to planetary disks. They are in general either circular or very slightly oval. In some cases the disk is sharply defined, in others it is hazy and nebulous at the edges. In some the disk shows a uniform surface, and in some it has an appearance which Sir J. Herschel describes by the term *curdled.*

There is no reason to doubt that the constitution of these objects is the same as that of other nebulæ, and that they are in fact clusters of stars which by mutual proximity and vast distance are reduced to the form of planetary disks.

These objects, which are not numerous, present some remarkable peculiarities of appearance and colour. It has been already observed that, although the companion of a red individual of a double star appears blue or green, it is not certain that this is its real colour, the optical effect of the strong red of its near neighbour being such as would render a white star apparently blue or green, and no example of any single blue or green star has ever been witnessed. The planetary nebulæ, however, present some very remarkable examples of these colours. Sir J. Herschel indicates a beautiful instance of this, in a planetary nebula situate in the southern constellation of the Cross. The apparent diameter is 12″, and the disk is nearly circular, with a well-defined outline, and a "fine and full blue colour verging somewhat upon green." Several other planetary nebulæ are of a like colour, but more faint.

The magnitudes of these stupendous masses of stars may be conjectured from their probable distances. One of the largest, and therefore probably the nearest of them, is situate near the star β Ursæ majoris (one of the pointers). Its apparent diameter is 2′ 40″. Now, if this were only at the distance of 61 Cygni, whose parallax is known (171), it would have a diameter equal to seven times that of the extreme limit of the solar system; but as it is certain that its distance must be many times greater, it may be conceived that its dimensions must be enormous.

730. **Annular nebulæ.**—A very few of the nebulæ have been observed to be annular. Until lately there were only four. The telescopes of Lord Rosse, have, however, added five to the number, by showing that certain nebulæ formerly supposed to be small round patches are really annular. It is extremely probable that many others of the smaller class of round nebulæ will prove to be annular, when submitted to further examination with telescopes of adequate power and efficiency.

731. **Spiral nebulæ.**—The discovery of this class of objects,

the most extraordinary and unexpected which modern researc has yet disclosed in stellar astronomy, is due to Lord Rosse. The general form and character may be conceived by referring to tho represented in Plate XXXIII. *figs.* 2 and 6, and Plate XXXV. *fig.* These extraordinary forms are so entirely removed from all analog with any of the phenomena presented either in the motions of th solar system, or the comets, or those of any other objects to whic observation has been directed, that all conjecture as to the physic condition of the masses of stars which could assume such form would be vain. The number of instances as yet detected in whic this form prevails is not great; but it is sufficient to prove th the phenomenon, whatever be its cause, is the result of the opera tion of some general law. It is pretty certain that when the sam powerful instruments which have rendered these forms visible i objects which had already been so long under the scrutiny of th most eminent observers of the last hundred years, including Sir W and Sir J. Herschel, aided by the vast telescopic powers at the disposition, without raising even a suspicion of their real form an structure, have been applied to other nebulæ, other cases of th same phenomenon will be brought to light. In this point of vie it is much to be regretted that the telescopes of Lord Rosse cann have the great advantage of being used under skies more favour able to stellar researches, since the discovery of such forms as thes not only requires instruments of such power as Lord Rosse alon possesses at present, but also the most favourable atmospheri conditions.

732. **Number of nebulæ.** — The number of these objects i countless. The catalogues of Sir J. Herschel contain above 400 of which the places are assigned, and the magnitudes, forms, an apparent characters described. As observers are multiplied, an the telescope improved, and especially when the means of obse vation have been extended to places that are more favourable fo such observations, it may be expected that the number observe will be indefinitely augmented.

733. **Remarkable nebulæ.** — Having noticed thus briefl the characters and appearances of the principal classes of thes objects, it will be useful to illustrate these general observations b reference to examples of nebulæ and clusters of each class, assign ing the position of each by its right ascension and north pola distance, and supplying, wherever it can be done on satisfactor authority, a telescopic view of such object. In the selection o these examples, it will be one of our chief purposes to show th extraordinary differences of form and structure which the sam object presents when viewed with telescopes of different powers The drawings of the same nebulæ, which have appeared in th

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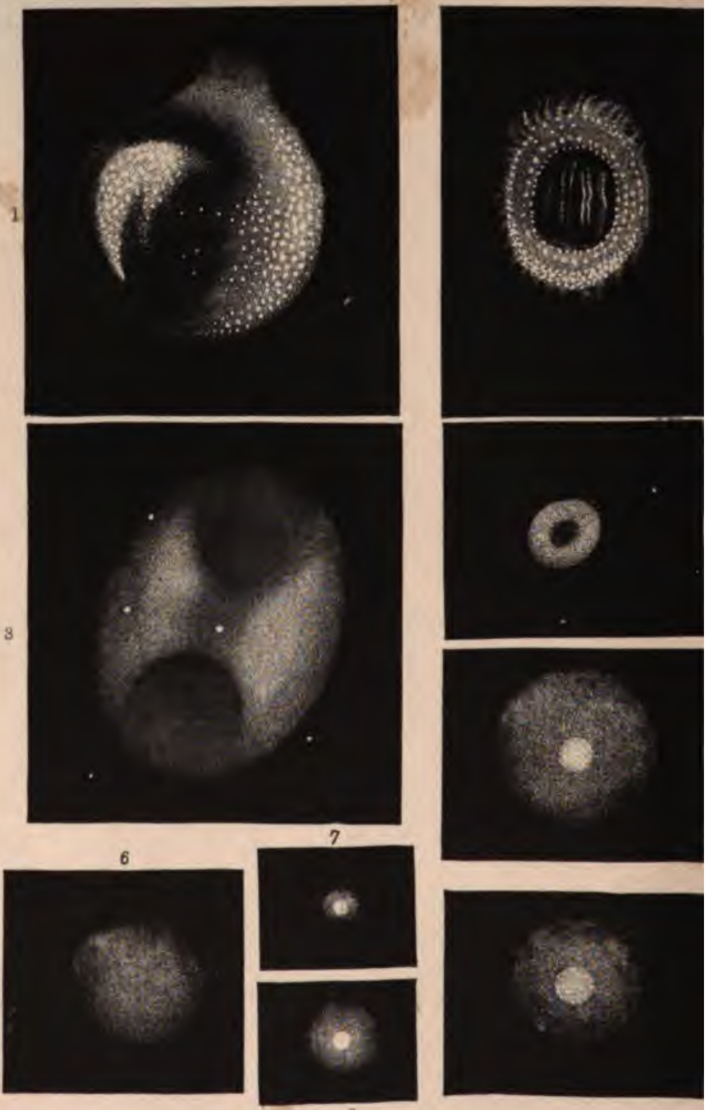

NEBULÆ AND CLUSTERS.

Telescopic views.

1 2, by the Earl of Rosse. 3 to 9, by Sir J. Herschel.

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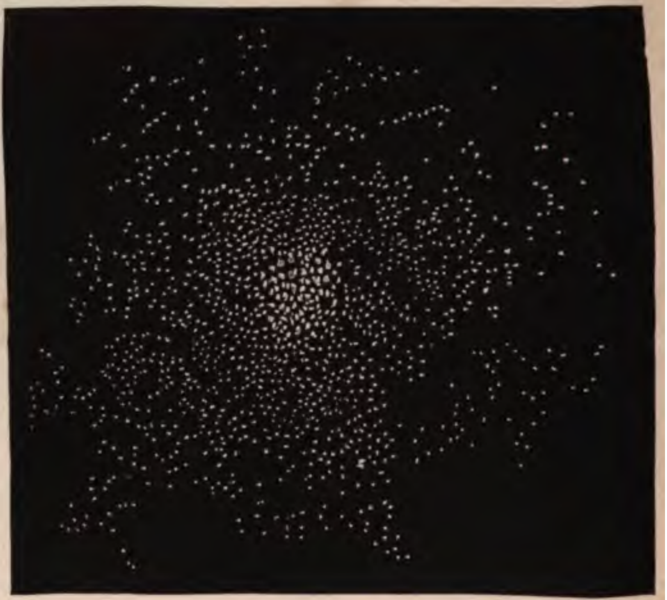

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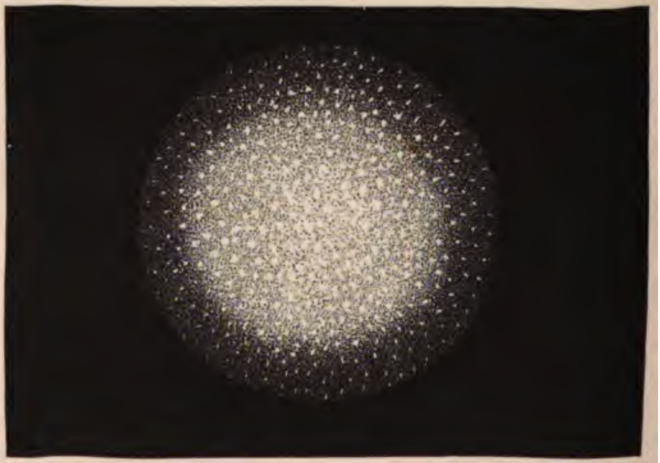

NEBULÆ AND CLUSTERS.

Telescopic views.

1. By the Earl of Rosse. 2. By Sir J. Herschel.

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XXXII.

1

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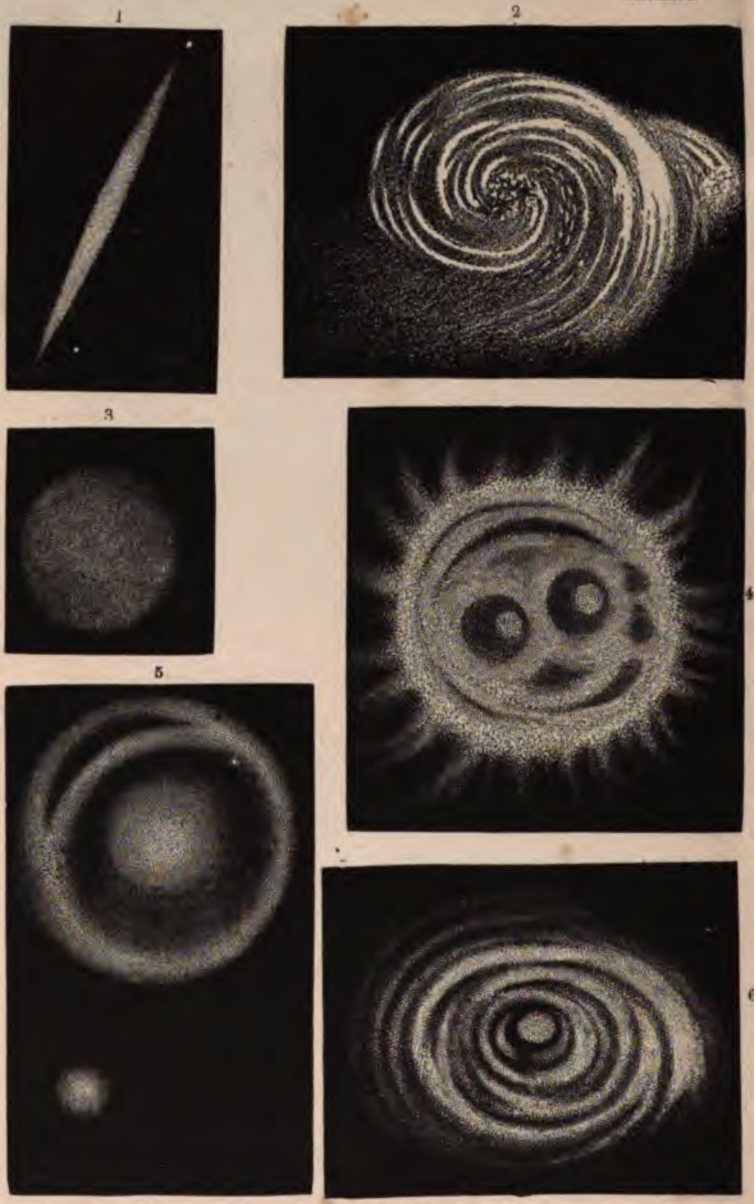
NEBULÆ AND CLUSTERS.

Telescopic views.

1. by the Earl of Rosse. 2. by Sir J. Herschel.

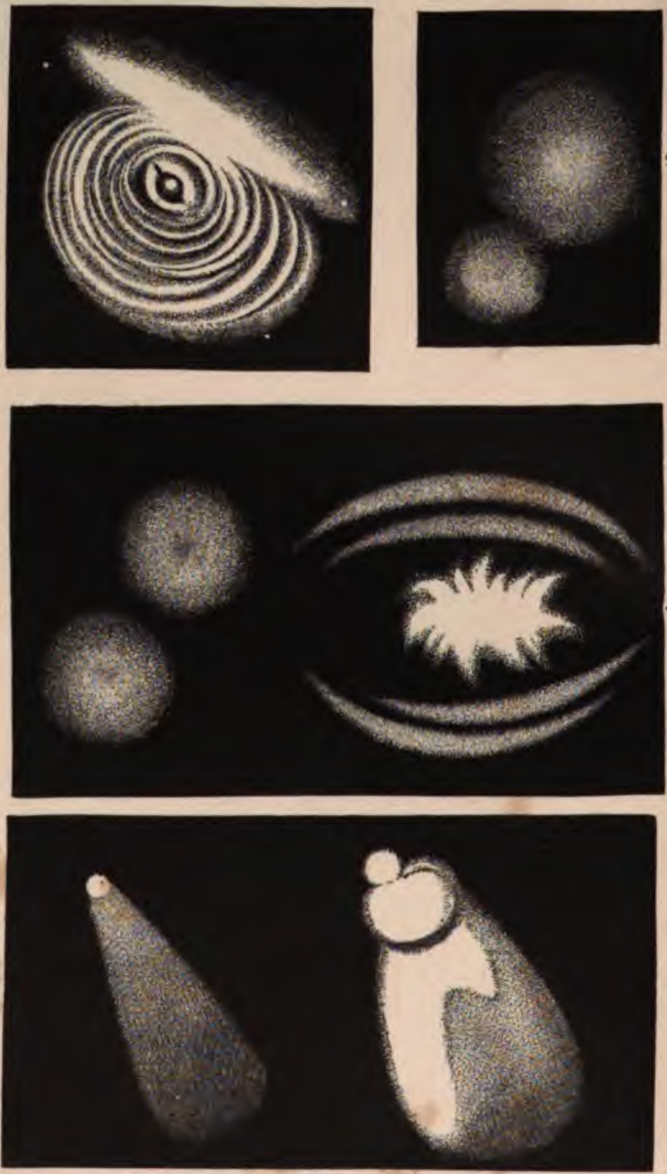


NEBULÆ AND CLUSTERS.

Telescopic views.

2, 4, 6, by the Earl of Rosse. 1, 3, 5, by Sir J. Herschel.

XXXIV.



1 2 3 4 5 6

NEBULÆ AND CLUSTERS.

Telescopic views.

1, 4, 6, by the Earl of Rosse 2, 3, 5, by Sir J. Herschel.

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XXXV.

NEBULÆ AND CLUSTERS.

Telescopic views.

1, 2, 3, 4, 5, 6, 8, 11, 12, 14, 15, by the Earl of Rosse. 7, 9, 10, 13, by Sir J. Herschel.

1

2

NEBULÆ AND CLUSTERS.

Telescopic views.

1. *The Dumb bell Nebula* by the Earl of Rosse. 2. Part of the great Nebula in Argo.

TELESCOPIC VIEW OF PART OF THE GREAT NEBULA IN ORION.

Philosophical Transactions, by Sir J. Herschel and the Earl of Rosse, supply numerous and instructive examples of this.

Plate XXX. *fig.* 6. R A $15^h\ 30^m\ 37^s$. N P D $83°\ 33'$. Diameter, 9^s R A. — Drawn by Sir J. Herschel, who describes it as a faint large round nebula, which, by attentive examination, may be seen to be composed of excessively minute stars, appearing like points rubbed out. It is, in fact, a globular cluster.

Plate XXXI. *fig.* 2. R A $21^h\ 26^m\ 13^s$. N P D $91°\ 26'$. Diameter, 6^s R A.—Drawn by Sir J. Herschel, who describes it as a most superb cluster of stars of the 15th magnitude, compressed towards the centre to a perfect blaze. It resembles a mass of fine luminous sand. It is resolvable with a six-inch aperture. The stars just visible with a nine-inch aperture (reflector).

Plate XXXI. *fig.* 1.—The same object as shown by the larger telescope of the Earl of Rosse. Lord Rosse thinks that no increased power is likely to alter materially its appearance. It would merely render the component stars brighter and less closely crowded.

Plate XXXII. *fig.* 2. R A $5^h\ 26^m\ 1^s$. N P D $68°\ 5'$. Length $4'$, breadth $3'$, oval form. — A fine object. (Sir J. Herschel.)

Plate XXXII. *fig.* 1.—The same object as shown by Lord Rosse's telescope. A considerable change of appearance is here produced by increased power, the oval resolvable nebula being changed into what the drawing represents. It is studded with stars mixed with a nebulosity, which a still higher power would evidently resolve into stars.

Plate XXXIII. *fig.* 5. R A $13^h\ 23^m\ 53^s$. N P D $42°\ 5'$. —This is, in many respects, one of the most remarkable and interesting of its class, and has been submitted to elaborate examination by all the eminent observers. The distance of the centre of the small nebula from that of the large one, is given by Messier as $4'\ 35''$, which may serve as a *modulus* for its other dimensions. It was described by Sir W. Herschel as a bright round nebula, surrounded by a halo or glory, and attended by a companion. Sir J. Herschel observed this object, and represented it as in the figure. He noticed the partial division of the ring as if it were split, as its most remarkable and interesting feature, and inferred that, supposing it to consist of stars, the appearance it would present to an observer, placed on a planet attached to one of them excentrically situate towards the north preceding quarter of the central mass, would be exactly similar to that of the milky way as seen from the earth, traversing in a manner precisely similar the firmament of large stars, into which the central cluster would be seen projected, and (owing to its greater distance) appearing like it to consist of stars much smaller than those in other parts of the heavens.

"Can it be," asks Sir J. Herschel, "that we have here a brother system, bearing a real physical resemblance and strong analogy of structure to our own?" Sir J. Herschel further argues, that all idea of symmetry caused by rotation must be relinquished, considering that the elliptical form of the inner subdivided portion indicates with extreme probability an elevation of that part above the plane of the rest; so that the real form must be that of a ring split through half its circumference, and having the split portions set asunder at an angle of 45°.

Plate XXXIII. *fig.* 2.—The same object as shown by Lord Rosse's telescope. This shows, in a striking manner, how entirely the appearances of these objects are liable to be varied by the increased magnifying power and greater efficiency of the telescope through which they are viewed. It is evident that very little resemblance or analogy is discoverable between *fig.* 2. and *fig.* 5. Lord Rosse, however, says that if Sir John Herschel's be placed as it would be seen with a Newtonian telescope, the bright convolutions of the spiral shown in his own would be recognised in the appearance which Sir J. Herschel supposed to be that which would be produced by a split or divided ring. Lord Rosse further observes that, with each increase of optical power, the structure of this object becomes more complicated and more unlike anything which could be supposed to be the result of any form of dynamical law of which we find a counterpart in our system. The connection of the companion with the principal nebula, of which there is not the least doubt, and which is represented in the sketch, adds, in Lord Rosse's opinion, if possible to the difficulty of forming any conceivable hypothesis. That such a system should exist without internal movement he considers in the last degree improbable. Our conception may be aided, by uniting with the idea of motion the effects of a resisting medium; but it is impossible to imagine such a system in any point of view as a case of mere statical equilibrium. Measurements he therefore considers of the highest interest, but of great difficulty.

Plate XXXV. *fig.* 1.—This object is the 99th in Messier's catalogue. The spiral form of the nebula, represented in Plate XXXIII. *fig.* 2, was discovered by Lord Rosse in the early part of 1845. In the spring of 1846, that represented in the present figure was discovered. The spiral form is here also presented, but of a different character. Lord Rosse conjectures that the nebulæ Nos. 2370 and 3239 of Herschel's southern catalogue, are very probably objects of a similar character. As Herschel's telescope did not reveal any trace of the form of this nebula, it is not surprising that it did not disclose the spiral form presumed to belong to the others, and it is not therefore unreasonable to hope, according to his Lordship, that whenever the southern hemisphere shall be re-examined with in-

struments of greater power, these two remarkable nebulæ will yield some interesting results.

Lord Rosse has discovered other spiral nebulæ, but they are comparatively difficult to be seen, and the greatest powers of the instrument are required to bring out the details.

Plate XXXIV. *fig.* 2. R A $9^h 24^m 15^s$. N P D $67° 53'$. Length $3'$. —This is described by Sir John Herschel as a very bright extended nebula, with an approach to a second nucleus, which, however, is very faint.

Plate XXXIII. *fig.* 6.—The same object as shown by Lord Rosse's telescope. This object was first observed with the great telescope, on the 24th of March, 1846, when a tendency to an annular or spiral form was discovered. On the 9th of March, 1848, in more favourable weather, the spiral form was distinctly seen in an oblique direction. The nebula was well resolved, particularly towards the centre, where it was very bright.

Plate XXXIII. *fig.* 1. R A $22^h 57^m 55^s$. N P D $78° 26'$. Length $2'$, breadth $30''$.—Described by Sir John Herschel as pretty bright and resolvable, and extended between two small stars, having two very small stars visible in it.

Plate XXXIV. *fig.* 1.—The same object as seen in Lord Rosse's telescope. It was frequently observed, both by Lord Rosse himself and several of his friends, and the drawing represents the form with great accuracy. It was doubtful whether the form was strictly spiral, or whether it was not more properly annular.

Plate XXXV. *fig.* 2. R A $1^h 25^m 57^s$. N P D $60° 4'$. Dimensions uncertain, but the diffused nebulæ estimated as extending through $15'$.—This object has been the subject of observation by all the eminent observers. Sir John Herschel describes it as enormously large, growing very gradually brighter towards the middle, and having a star of the 12th magnitude, north, following the nucleus, and being characterised by irregularities of light, and even by feeble subordinate nuclei and many small stars. The drawing represents it as seen with the more powerful telescope of Lord Rosse. A tendency to a spiral form was distinctly seen on the 6th, 10th, and 16th of September, 1849. The brightest of the spiral arms was that marked α, that marked δ was pretty bright, but short; β was distinct, and η only suspected; the branch γ was faint. The whole object was involved in a faint nebulosity, which probably extends past several knots which lie about it in different directions.

Plate XXXIV. *fig.* 3. R A $7^h 16^m 41^s$. N P D $60° 15'$.—This is described by Sir John Herschel as a curious bright double or an elongated bicentral nebula.

Plate XXXIV. *fig.* 4.—The same object as shown by Lord Rosse's telescope, on the 22nd of December, 1848. A bright star was visible

between the nebulæ from which tails and curved filaments issued. The existence of an annulus surrounding the two nebulæ was suspected.

Plate XXXV. *fig.* 14. R A 11ʰ 11ᵐ 36ˢ. N P D 76° 9′. Length 4′.—Described by Sir John Herschel, as large, elliptical in form, with a round nucleus, and growing gradually brighter towards the middle.

Plate XXXV. *fig.* 3.—The same object as shown by Lord Rosse's telescope, on the 31st of March, 1848. Described as a curious nebula, nucleus resolvable, having a spiral or annular arrangement about it. It was also observed with the same results on the 1st and 3rd of April.

Plate XXXV. *fig.* 5. R A 15ʰ 2ᵐ 38ˢ. N P D 33° 42′. Length 50″. Breadth 20″.—This nebula was not figured by Sir John Herschel, but is described by him as an object very bright, and growing much brighter towards the middle. The drawing, *fig.* 5, represents the object as seen in Lord Rosse's telescope, in April 1848. It is described by Lord Rosse as a very bright resolvable nebula, but that none of the component stars could be distinctly seen even with a magnifying power of 1000. A perfectly straight longitudinal division appears in the direction of the major axis of the ellipse. Resolvability was strongly indicated towards the nucleus. According to Lord Rosse, the proportion of the major axis to the minor axis was 8 to 1; much greater than the estimate of Sir John Herschel.

Plate XXXV. *fig.* 10. R A 12ʰ 35ᵐ 21ˢ. N P D 56° 41′.—Described by Sir John Herschel as a nebula of enormous length, extending across an entire field of 15′, the nucleus not being well defined. It was preceded by a star of the tenth magnitude, and that again by a small faint round nebula, the whole forming a fine and very curious combination.

Plate XXXV. *fig.* 4.—The same object as shown by Lord Rosse's telescope on the 19th of April, 1849. The drawing is stated to be executed with great care, and to be very accurate. A most extraordinary object, masses of light appearing through it in knots.

Plate XXXIV. *fig.* 5. R A 6ʰ 31ᵐ 36ˢ. N P D 81° 8′.—Described by Sir John Herschel as a star of the 12th magnitude, with a bright cometic branch issuing from it, 60″ in length, forming an angle of 60° with the meridian, passing through it. The star is described as ill defined, the apex of the nebula coming exactly up to it, but not passing it.

Plate XXXIV. *fig.* 6.—The same object as seen with Lord Rosse's telescope on the 16th of January, 1850. Lord Rosse observed that the two comparatively dark spaces, one near the apex and the other near the base of the cone, are very remarkable.

Plate XXXIII. *fig.* 3. R A $11^h 6^m 34^s$. N P D $34° 14'$ Diameter 19^s of time in R A.—Described by Sir John Herschel as a large uniform nebulous disk, very bright and perfectly round, but sharply defined, and yet very suddenly fading away into darkness. A most extraordinary object.

Plate XXXIII. *fig.* 4.—The same object as shown by Lord Rosse's telescope. Two stars considerably apart, seen in the central part of the nebula. A dark penumbra around each spiral arrangement with stars as apparent centres of attraction. Stars sparkling in it and in the nebula resolvable. Lord Rosse saw two large and very dark spots in the middle, and remarked that all round its edge the sky appeared darker than usual.

Plate XXXV. *fig.* 11. R A $7^h 35^m 23^s$. N P D $104° 24'$. Diameter $3^s{\cdot}75$ of time.—Described by Sir John Herschel as a planetary nebula, of a faint equal light, and exactly round, having a very minute star a little north of the centre. Very velvety at the edges. In the telescope of Lord Rosse, however, it appears as an annular nebula as represented in the figure, with two stars within it.

Plate XXXV. *fig.* 7. R A $23^h 19^m 3^s$. N P D $48° 14'$. Diameter $12''$.—Figured by Sir John Herschel, who describes it as a fine planetary nebula. With a power of 240 it was beautifully defined, light, rather mottled, and the edges the least in the world unshaped. It is not nebulous, but looks as if it had a double outline, or like a star a little out of focus. It is perfectly circular.

Plate XXXV. *fig.* 6.—The same object as shown in Lord Rosse's telescope, on the 16th—19th of December, 1848. A central dark spot surrounded by a bright annulus.

Plate XXXV. *fig.* 9. R A $20^h 56^m 28^s$. N P D $101° 55'$. Diameter $10''$ to $12''$ according to Herschel, but $25''$ by $17''$ according to Struve, who gives it a more oval form.—This figure is that given by Sir John Herschel, who describes it as a fine planetary nebula with equable light and bluish white colour.

Plate XXXV. *fig.* 8.—The same object as shown by Lord Rosse's telescope. Like a globe surrounded by a ring such as that of Saturn, the usual line being in the plane of the ring.

Plate XXXV. *fig.* 13. R A $7^h 20^m 55^s$. N P D $68° 48'$.—Described by Sir John Herschel as a star exactly in the centre of a bright circular atmosphere $25''$ in diameter, the star being quite stellar, and not a mere nucleus, and is a most remarkable object.

Plate XXXV. *fig.* 12.—The same object as shown by Lord Rosse's telescope on the 20th of February, 1849; described by him as a most astonishing object. It was examined in January

1850, with powers of 700 and 900, when both the dark and bright rings seemed unequal in breadth.

Plate XXXV. *fig.* 15. R A $5^h\ 28^m\ 35^s$. N P D 96° 1′.—The star ι Orionis involved in a feeble nebula 3′ in diameter. (Sir J. Herschel.) The drawing shows this as seen with Lord Rosse's telescope.

Plate XXX. *fig.* 3. R A $19^h\ 53^m\ 27^s$. N P D 67° 40′.—Drawn by Sir John Herschel, who describes it as a nebula shaped like a dumb-bell, double-headed shot, or hour-glass, the elliptic outline being completed by a more feeble nebulous light. The axis of symmetry through the centres of the two chief masses inclined at 30° to the meridian. Diameter of elliptic light from 7′ to 8′. Not resolvable, but four stars are visible on it of the 12th, 13th, and 14th magnitude. The southern head is denser than the northern. This extraordinary object was also observed by Sir W. Herschel, who recognised the same peculiar form. Sir J. Herschel considers that the most remarkable circumstance attending it is the faint nebulosity which fills up the lateral concavities of its form, and in fact converts them into protuberances, so as to render the whole outline a regular ellipse, having for its shorter axis the common axis of the two bright masses. If it be regarded as a mass in rotation, it is around this shorter axis it must revolve. In that case, he considers that its real form must be that of an oblate spheroid; and as it does not follow that the brightest portions must be of necessity the densest, this supposition would not be incompatible with dynamical laws, at least supposing its parts to be capable of exerting pressure on each other. But if it consist of distinct stars this cannot be admitted, and we must then have recourse to other suppositions to account for the maintenance of its form. Sir John Herschel, it will be observed, failed to resolve this nebula.

Plate XXXVI. *fig.* 1.—The same object as shown by the telescope of Lord Rosse, three feet aperture, twenty-seven feet focal length.

Plate XXX. *fig.* 1.—The same object as shown with the great telescope of Lord Rosse, six feet aperture, fifty-three feet focal length.

The difference between these two representations and that given by Sir John Herschel of the same object, will illustrate in a very striking manner the observations already made on the effects of different magnifying and defining powers upon the appearance of the object under examination. These three figures could scarcely be conceived to be representations of the same object.

To explain the difference observable between the drawing, Plate XXXVI. *fig.* 1, made with the smaller telescope, and the drawing,

Plate XXX *fig.* 1, made with the larger instrument, Lord Rosse observes, that while the application of a high magnifying power brings out minute stars not visible with lower powers, it completely extinguishes nebulosity which the lower powers render visible. The optical reason for this will be easily perceived; the circumstance was nevertheless overlooked when the observations were made from which the drawing, Plate XXXVI. *fig.* 1 was taken. Only one magnifying power, and that a very high one, was used on that occasion, the consequence of which was that, although the two knobs of the dumb-bell were more fully resolved, the nebulous matter filling the intermediate space, which Herschel considered to be the most remarkable feature of this nebula, was entirely extinguished in the optical image. If on that occasion a second eye-piece had been used of lower power, the intermediate nebulous matter would have been seen as represented in the drawing, and the drawing would be as perfect as, and nearly identical with, that obtained with the greater telescope, Plate XXX. *fig.* 1, a lower power being used.

It will be observed that the general outline of this remarkable object, which is so geometrically exact as seen with the inferior power used by Sir John Herschel, is totally effaced by the application of the higher powers used by Lord Rosse and consequently, Sir John Herschel's theoretical speculations based upon this particular form must be regarded as losing much of their force, if not wholly inadmissible; and this is an example proving how unsafe it is to draw any theoretical inferences from apparent peculiarities of form or structure in these objects, which may be only the effect of the imperfect impressions we receive of them, and which, consequently, disappear when higher telescopic powers are applied. The case of the nebula represented in Plate XXXIII. *figs.* 2 and 5, presents another striking example of the force of these observations.

Plate XXX. *fig.* 4. RA 18^h 48^m 19^s. NPD 57° 9′.—This object, drawn by Sir J. Herschel, is the annular nebula between β and γ Lyræ. He estimates its diameter at $6^s.5$ of time. The annulus is oval, its longer axis being inclined at 57° to the meridian. The central vacuity is *not black*, but filled with a nebulous light. The edges are not sharply cut off, but ill defined; they exhibit a curdled and confused appearance, like that of stars out of focus. He considers it not well represented in the drawing.

Plate XXX. *fig.* 2.—The same object as shown in the telescope of Lord Rosse. This drawing was made with the smaller telescope, three feet aperture, before the great telescope had been erected. The nebula was observed seven times in 1848, and once in 1849. With the large telescope, the central opening showed

considerably more nebulosity than it appeared to have with the smaller instrument. It was also noticed that several small stars were seen around it with the large instrument which did not appear with the smaller one, from which it was inferred that the stars seen in the dark opening of the ring may possibly be merely accidental, and have no physical relation to the nebula. In the annulus near the extremity of the minor axis, several minute stars were visible.

Plate XXX. *fig.* 5. R A 13^h 30^m 29^s. N P D $107°$ $10'$. Diameter of faint nebula $2'$. Diameter of bright part, $10''$ or $15''$. —Described as a faint large nebula, losing itself quite imperceptibly; a good type of its class. (Herschel.)

Plate XXX. *fig.* 7. R A 17^h 45^m 57^s. N P D $66°$ $54'$. Perceptible disk $1''$, or $1''\cdot5$ diameter. Surrounded by a very faint nebula. —A curious object. (Herschel.)

Plate XXX. *fig.* 8. R A 19^h 41^m 7^s. N P D $39°$ $50'$.—A most curious object. A star of the 11th magnitude, surrounded by a a very bright and perfectly round planetary nebula of uniform light. Diameter in R A $3^s\cdot5$, perhaps a very little hazy at the edges. (Herschel.)

Plate XXX. *fig.* 9. R A 10^h 30^m 4^s. N P D $35°$ $46'$.—A bright round nebula, forming almost a disk $15''$ diameter, surrounded by a very feeble atmosphere. (Herschel.)

734. **Large and irregular nebulæ.**—All the nebulæ described above, are objects generally of regular form and subtending small visual angles. There are others, however, of a very different character, which cannot be passed without some notice. These objects cover spaces on the firmament, many nearly as extensive as, and some much more extensive than, the moon's disk. Some of them have been resolved. Of those which are larger and more diffused, some exhibit irregularly shaped patches of nebulous light, affecting forms resembling those of clouds, in which tracts are seen in every stage of resolution, from nebulosity irresolvable by the largest and most powerful telescopes, to stars perfectly separated like parts of the milky way, and "clustering groups sufficiently insulated and condensed to come under the designation of irregular and, in some cases, pretty rich clusters. But besides these there are also nebulæ in abundance, both regular and irregular; globular clusters in every state of condensation, and objects of a nebulous character quite peculiar, which have no analogy in any other part of the heavens." *

735. **Rich cluster in the Centaur.**—The star ω Centauri presents one of the most striking examples of the class of large diffused

* Herschel, *Outlines of Astronomy.*

clusters. It is nearly round, and has an apparent diameter equal to two-thirds of that of the moon. This remarkable object was included in Mr. Dunlop's catalogue (*Phil. Trans.* 1828); but it is from the observations of Sir John Herschel at the Cape that the knowledge of its splendid character is derived. That astronomer pronounces it, beyond all comparison, the richest and largest object of the kind in the heavens. The stars composing it are literally innumerable; and as their collective light affects the eye hardly more than that of a star of the fifth magnitude, the minuteness of each of them may be imagined. The apparent magnitude of this object is such that, when it was concentric with the field of Sir J. Herschel's 20-ft. telescope, the straggling stars at the edges were beyond the limit of the field. In stating that the diameter is two-thirds of the moon's disk, it must be understood to apply to the diameter of the condensed cluster, and not to include the straggling stars at the edges. When the centre of the cluster was brought to the edge of the field, the outer stars extended fully half a radius beyond the middle of it.*

The appearance of this magnificent object resembles that shown in Plate XXXI. *fig.* 1, only that the stars are much more densely crowded together, and the outline more circular, indicating a pretty exact globe as the real form of the mass.

736. **The great nebula in Orion.** — The position of this extraordinary object is in the sword handle of the figure which forms the constellation of Orion. It consists of irregular cloud-shaped nebulous patches, extending over a surface about 40′ square; that is, one whose apparent breadth and height exceed the apparent diameter of the moon by about one-third, and whose superficial magnitude is therefore rather more than twice that of the moon's disk. Drawings of this nebula have been made by several observers, and engravings of them have been already published in various works.

In Plate XXXVII. is given a representation of the central part of this object. The portion here represented measures about 27′ in length and 25′ in breadth; being about one-sixth less than the diameter of the moon. An engraving upon a very large scale of the entire extent of the nebula, with an indication of the various stars which serve as landmarks to it, may be seen by reference to Sir J. Herschel's "*Cape Observations*," accompanied by the interesting details of his observations upon it.

Sir J. Herschel describes the brightest portion of this nebula as resembling the head and yawning jaws of some monstrous animal, with a sort of proboscis running out from the snout. The

* *Cape Observations*, p. 21.

stars scattered over it probably have no connection with it, and are doubtless placed much nearer to our system than the nebula, being visually projected upon it. Parts of this nebula, when submitted to the powers of Lord Rosse's telescopes, show evident indications of resolvability.

737. **The great nebula in Argo.** — This is an object of the same class, and presenting like appearances; it is diffused around the star η in the constellation here named, and formed a special subject of observation by Sir J. Herschel during his residence at the Cape. An engraving of it on a large scale, giving all its details, may be seen in the "*Cape Observations.*" The position of the centre of the nebula is, R A $10^h\ 39^m\ 47^s$; N P D $148°\ 38'$.

This object consists of diffused irregular nebulous patches, extending over a surface measuring nearly $7'$ (time) in right ascension, and $68'$ in declination; the entire area, therefore, being equal to a square space whose side would measure one degree. It occupies, therefore, a space on the heavens about five times greater than the disk of the moon.

A part of the nebula immediately surrounding the central star is represented in Plate XXXVI. *fig.* 2. The space here represented measures about one-fourth of the entire extent of the nebula in declination, and one-third in right ascension, and about a twelfth of its entire magnitude.

No part of this remarkable object has shown the least tendency to resolvability. It is entirely compressed within the limits of that part of the milky way which traverses the southern firmament, the stars of which are seen projected upon it in thousands. Sir J. Herschel has actually counted 1200 of these stars projected upon a part of this nebula measuring no more than $28'$ in declination and $32'$ in right ascension, and he thinks that it is impossible to avoid the conclusion, that in looking at it we see through and beyond the milky way, far out into space through a starless region, disconnecting it altogether with our system.

738. **Magellanic clouds.** — These are two extensive nebulous patches also seen on the southern firmament, the greater called the *nubecula major*, being included between R A $4^h\ 40^m$, and $6^h\ 0^m$ and N P D $156°$ and $162°$, occupying a superficial area of 42 square degrees; and the other called the *nubecula minor*, being included between R A $0^h\ 28^m$ and $1^h\ 15^m$ and between N P D $162°$ and $165°$, covering about 10 square degrees.

These nebulæ consist of patches of every character, some irresolvable, and others resolvable in all degrees, and mixed with clusters, having all the characters already explained in the cases of the large diffused nebulæ described above. So great is the number of distinct nebulæ and clusters crowded together in these

tracks of the firmament, that 278, besides 50 or 60 outliers, have been enumerated by Sir J. Herschel, within the area of the nubecula major alone.

CHAPTER XXIII.

SYNOPSIS OF THE SOLAR SYSTEM.

739. **Planetary data.** — Having explained in a former part of the volume the principal circumstances attending the physical condition and motion of the different bodies of the solar system, it remains to bring them into juxtaposition, to view them collectively, and to supply, in tabulated forms, those numerical data which at any given time may assist in determining their positions and motions.

We shall therefore give in this concluding chapter a short explanation of these data or elements, together with a few of the methods which may be useful in an investigation of the movements of the various members of the system. Our limits, however, will not permit any lengthened detail; those of our readers who desire to enter more fully into the mathematical study of the subject, are therefore referred to those special works on the different branches of the science which have been prepared by the principal astronomers of England and the Continent.

Planetary data may be resolved into three classes: —

I. Those which determine the orbit.

II. Those which determine the place of the body in the orbit.

III. Those which determine the conditions which are independent of the orbit.

In this section we have also inserted further explanations on some important points, which will doubtless tend to elucidate the respective subjects.

I. *Data which determine the form, magnitude, and position of the orbits of the planets.*

740. **Form of the orbit determined by the excentricity.**— It is well understood (284) that the form of an ellipse depends on the excentricity, all ellipses with the same excentricity, however they may differ in magnitude, having the same form.

Let a = the mean distance, c = the distance of the centre of the orbit from the centre of the sun, and e = the excentricity. We shall then have

$$e = \frac{c}{a}, \qquad c = a \times e.$$

The values of e, in the cases of all the principal planets, Mercury excepted, are less than $\frac{1}{10}$. In the case of Mercury it is about $\frac{1}{5}$, and in the larger planets $\frac{1}{20}$.

In the case of the planetoids, the excentricities are subject to great and exceptional variation, amounting in the case of Polyhymnia to $\frac{1}{3}$, whilst in that of Harmonia it amounts to about $\frac{1}{22}$.

741. **Magnitude determined by semi-axis major.** — As the excentricity determines the form, the semi-axis determines the magnitude, of the orbit. This quantity forms in other respects a very important planetary element, since upon it is dependent the periodic time, and consequently the mean angular and mean linear velocity in the orbit.

742. **Position of the plane of the orbit.** — The plane of the orbit must always pass through the centre of the sun, which is therefore the common point at which the planes of all the planetary orbits intersect. But to define the position of the plane of any orbit something more is necessary. If the plane of the earth's orbit be provisionally assumed as a fixed plane, (which however it is not), the positions of the planes of the orbits of the planets, severally, with relation to it, will be determined, 1st, by the angle at which they intersect it, and, 2ndly, by the direction of the line of intersection.

743. **Inclinations of the orbits.** — The angles which the planes of the orbits of the principal planets form with the plane of the ecliptic, are less than 4°, excepting the planet Mercury, whose orbit is inclined to the ecliptic about 7°. The planetoids, however, are very exceptional, the orbit of Pallas having an inclination of $34\frac{1}{2}°$; the inclinations of the others varying from 26° to less than 1°.

744. **Line of nodes.** — The inclination is not enough to determine the position of the plane of the orbit, for it is evident that an infinite variety of different planes may be inclined at the same angle to the ecliptic. If, however, the direction of the line of intersection of the plane of the orbit with the plane of the ecliptic (which line must always pass through the centre of the sun) be also defined, the position of the plane of the orbit will be determined. This line of intersection is called the *line of nodes*, being the direction in which the nodes of the planet's orbit are seen from the sun. If an observer be imagined to be stationed at the centre of the sun, he will be in this line, and the nodes will be viewed by him in opposite directions along this line, the ascending node (293) being viewed in one direction, and the descending node in the other.

745. **Longitude of ascending node.**—It has been customary to define the direction of the line of nodes by the angle which the

direction of the ascending node, seen from the sun, makes with the direction of the "first point of Aries," or, what is the same, by its heliocentric longitude.

The position of the plane of the orbit is therefore determined by its *inclination* and the *longitude of the ascending node.*

746. **Longitude of perihelion.**—These data, however, are still insufficient to determine the position of the orbit. They would be sufficient if the orbit were circular, since a circle is symmetrical with relation to its centre. But the orbit being an ellipse, the major axis may have an infinite variety of different directions, all of which shall pass through the sun's centre, and all of which shall be in the same plane. After defining, therefore, the position of the plane of the orbit, it is necessary to determine the position of the orbit upon that plane, and this is determined by the direction of its major axis, just as the plane itself was determined by the direction of the line of nodes, and as the latter was determined by the heliocentric longitude of the ascending node; the position of the orbit upon its plane is determined by the heliocentric longitude of perihelion (286).

747. **Five elements which determine the orbit.**—The orbit of a planet is therefore determined, in form, magnitude, and position, by the five following data, which are called its ELEMENTS:—

1. The semi-axis, or mean distance - - - a
2. The excentricity - - - - - e
3. The inclination - - - - - i
4. The longitude of the ascending node - - ν
5. The longitude of perihelion - - - π

The excentricity is sometimes expressed by the angle ϕ, of which e is the sine, which is called the "angle of excentricity."

748. **Elements subject to slow variation — Epoch.**—If the elements of the orbit were invariable, they would be always known when once ascertained. But although for short intervals of time they may, without sensible error, be regarded as constant, some of them are subject to slow variations, which, after long intervals, such, for example, as centuries, completely change the orbits. These variations have been calculated with surprising precision, and are, moreover, found to be periodical, although their periods are in general of such magnitude as to surpass not only the limits of human life, but those of all human record.

Since, therefore, the planetary orbits are thus subject to a slow but constant change, it is necessary in assigning their elements to assign also the date at which the orbits had these elements. When the rates at which the elements severally vary are known, their

Fig. 103.

values at any assigned date being given, their values at any other date, anterior or posterior, can be determined.

The date at which the elements of the orbits have had the values assigned to them is technically called the EPOCH.

749. **Mean distances of the planets.**—In Table I. at the end of this chapter, the mean distances of the planets are given, that of the Earth being unity. The planets will be found in this table arranged in the order of their mean distances from the sun; the reader can thus see at a glance the relative position in the solar system of each member of the planetary group, with the exception only of Vulcan, which though believed by many to have a real existence, is not yet sufficiently recognised to be incorporated in a synoptical table of the established planets.

In Table II. the distances of the planets from the sun and earth are given in millions of miles.

To illustrate the relative mean distances of the planets from the sun, and from each other, we have delineated, nearly in their proper proportions, the mean distances of the principal planets, and the planetoids or asteroids, in *fig.* 103.

II. *Data to determine the place of the planet.*

750. **By the epoch and the mean daily motion.**—The orbit being defined in magnitude, form, and position, it is necessary to supply the data by which the position of the planet in it at any assigned time may be found. It will be sufficient for this to assign the position which the planet had at the EPOCH, and the periodic time, from which the mean daily motion of the planet can be inferred. By means of this motion, the mean place of the planet for any given time anterior or posterior to the epoch can be determined.

751. **The equation of the centre.**—To find the true place of the planet a further correction, however, is necessary. The angular velocity of the planet referred to the sun is not uniform, being greatest at perihelion and least at aphelion. The difference between the position which the planet would have, as seen from the sun, if its angular motion were uniform and that which it actually has, is called the "*equation of the centre*," and tables are computed by which this correction for each planet may be made, so that, the mean place of the planet in its orbit being determined, the true place may be found.

752. **Sidereal and equinoxial periods.**—The SIDEREAL PERIOD, or the time which the planet takes to make a complete revolution round the sun, will be found in the table of the principal elements.

If the equinoxial points were fixed, the sidereal period would be equal to the interval between two successive returns of the planet to the same equinoxial point. But the equinoxial points are subject, as already explained (174), to a very slow retrograde motion, in virtue of which the first point of Aries, from which right ascensions and longitudes are measured, moves annually from the east to west upon the ecliptic through a space a little less than a minute. A planet, therefore, departing from the vernal equinoxial point, and moving constantly from west to east, will return to that point before it completes its revolution, inasmuch as that point moving in the contrary direction meets it before its return to the point of departure.

It follows from this, that the interval between two successive returns to the vernal equinoxial point is a little less than the sidereal period. This interval is called the *equinoxial period.*

753. **Perihelion and aphelion distances.**—Let the extreme and mean distances of the earth from the sun, expressed in millions of miles, be

$$d = \text{mean distance}$$
$$d' = \text{least distance}$$
$$d'' = \text{greatest distance:}$$

we shall then have, according to what has been already explained and proved,

$$d = 91\tfrac{1}{2} \quad d' = 91\tfrac{1}{2} \times (1 - e) \quad d'' = 91\tfrac{1}{2} \times (1 + e),$$

the value of e in the case of the earth being 0·0167705.

Let the mean and extreme distances of a planet from the sun be in like manner expressed by D, D′ D″ in millions of miles, and we shall have

$$\text{D} = 91\tfrac{1}{2}\,a \quad \text{D}' = 91\tfrac{1}{2}\,a \times (1 - e) \quad \text{D}'' = 91\tfrac{1}{2}\,a \times (1 + e).$$

The distance S of a planet from the earth at superior conjunction being equal to the sum of the distances of the earth and planet from the sun, we shall have

$$S = D + d.$$

This will vary, because the distances from the sun vary. It will be greatest when the earth and planet are both in aphelion, and least when they are both in perihelion. If S'', therefore, express the greatest, and S' the least possible distance of the planet when in conjunction, the mean being expressed by S, we shall have

$$S'' = D'' + d'' \qquad S' = D' + d'.$$

The distance of an inferior planet from the earth, when in inferior conjunction, is found by subtracting the planet's distance from the sun from the earth's distance. If O express the mean distance of the planet in inferior conjunction from the earth, we shall have

$$O = d - D.$$

The distance will vary according to the relative positions of the axes of the elliptic orbits, and will evidently be greatest when the earth is in aphelion and the planet in perihelion, and least when the earth is in perihelion and the planet in aphelion. If O'' and O' then express, as before, the greatest and least possible distances of the planet in inferior conjunction, we shall have

$$O'' = d'' - D' \qquad O' = d' - D''.$$

The distance of a superior planet in opposition is found by subtracting the earth's distance from the planet's distance; and it may in like manner be shown that the mean and extreme distances of the planet in opposition from the earth will be

$$O = D - d \qquad O'' = D'' - d' \qquad O' = D' - d''.$$

III. *Conditions affecting the physical and mechanical state of the planet independently of its orbit.*

754. In the preceding chapters we have generally explained and illustrated the methods by which the real magnitudes, masses, densities, diurnal rotation, and superficial gravity of the planets are determined. These data and some others are brought together and arranged in juxtaposition, being expressed numerically, with relation to the most generally useful units, in the Tables III. IV. and V.

The methods of computing many of the quantities and magnitudes given in the several columns of these Tables have been already explained. Some of them, however, require further elucidation.

In several parts of this volume reference is made to the linear value of an arc at a distant object; it would therefore be useful here to give the methods for its determination.

755. **Relative magnitudes of arcs of 1°, 1′, and 1″, and the radius.**—It is proved in geometry that the length of the entire circumference of a circle whose radius is expressed by 1·000 exceeds 6·283 by less than the 5000th part of the radius. As the exact length of the circumference does not admit of any numerical expression, it will therefore be sufficient for all practical purposes to take 6·283 to express it.

If d, m, and s express respectively the actual lengths or *linear values* of a degree, a minute, and a second of a circle, the length of whose radius is expressed by r, we shall therefore have the following numerical relations between these several lengths:—

$$60 \times s = m, \qquad 60 \times m = d, \qquad 3600 \times s = d$$
$$360\, d = 6{\cdot}283\, r, \qquad 360 \times 60 \times m = 21600 \times m = 6{\cdot}283 \times r,$$
$$21600 \times 60 \times s = 1296000 \times s = 6{\cdot}283 \times r,$$

and from these may be deduced the following:

$$r = 57{\cdot}3 \times d = 3437{\cdot}8 \times m = 206265 \times s.$$

By these formulæ respectively the length of the radius may be computed when the linear value of an arc of 1°, 1′, or 1″ is known.

In like manner, if the length of the radius r be given, the linear value of an arc of 1°, 1′, or 1″ may be computed by the formulæ

$$d = \frac{1}{57{\cdot}3} \times r, \qquad m = \frac{1}{3437{\cdot}8} \times r, \qquad s = \frac{1}{206265} \times r.$$

756. **The linear and angular magnitudes of an arc.**—By the linear magnitude of an arc is to be understood its actual length if extended in a straight line, or the number expressing its length in units of some known modulus of length, such as an *inch*, a *foot*, or a *mile*. By its angular magnitude is to be understood the angle formed by two lines or radii drawn to its extremities from the centre of the circle of which it forms a part, or the number expressing the magnitude of this angle in angular units of known value, as degrees, minutes, and seconds.

757. **Of the three following quantities,—the linear value of an arc, its angular value, and the length of the radius,—any two being given, the third may be computed.**—Let α express the angular, and a the linear value of the arc, and r the radius.

1st. Let α and a be given to compute r. By dividing a by α we shall find the linear value of 1°, 1′, or 1″, according as α is expressed

in degrees, minutes, or seconds, and r may then be computed by (755). Thus, according to the angular units in which α is expressed, we shall have

$$r=\frac{a}{\alpha^{\circ}}\times 57\cdot3 \qquad r=\frac{a}{\alpha'}\times 3437\cdot8 \qquad r=\frac{a}{\alpha''}\times 206265.$$

2ndly. Let a and r be given to compute α. By (755) the linear values of 1°, 1′, or 1″ may be computed, since r is given, and by dividing a by one or other of these values, α will be found: thus we shall have

$$\alpha^{\circ}=\frac{a}{\frac{1}{57\cdot3}\times r} \qquad \alpha'=\frac{a}{\frac{1}{3437\cdot8}\times r} \qquad \alpha''=\frac{a}{\frac{1}{206265}\times r}$$

3rdly. Let α and r be given to compute a. By (755), as before, the linear values of 1°, 1′, or 1″ may be found, and by multiplying one or other of these by α the value of a will be obtained: thus we shall have

$$a=\frac{1}{57\cdot3}\times r\times\alpha^{\circ} \qquad a=\frac{1}{3437\cdot8}\times r\times\alpha' \qquad a=\frac{1}{206265}\times r\times\alpha''.$$

758. **Method of computing the extreme and mean apparent diameters.**—The real diameter δ being ascertained by the methods explained in (757), α being the apparent diameter, and r the distance, the extreme variation of the apparent diameter may be found from a comparison of the real diameter with the extreme and mean distances of the object. Supposing D to represent the mean distance, D′ the least, and D″ the greatest distance, we have thus (757)

$$\alpha=\frac{\delta}{D}\times 206265 \qquad \alpha'=\frac{\delta}{D'}\times 206265 \qquad \alpha''=\frac{\delta}{D''}\times 206265.$$

759. **Surfaces and volumes.**—The surface of the earth consists of 197 millions of square miles, and its volume of 259,800 millions of cubic miles. Let these numbers be expressed respectively by E′ and E″. Since, then, the surfaces of spheres are as the squares, and their volumes as the cubes of their diameters, if Δ' express the surface, and Δ'' the volume of a planet related to those of the earth as an unit, and δ' the surface in millions of square miles, and δ'' the volume in billions of cubic miles, we shall have

$$\Delta'=\Delta^2 \qquad \Delta''=\Delta^3$$
$$\delta'=\Delta'\times E' \qquad \delta''=\Delta''\times E''.$$

760. **The Masses.**—If M and M′ be any two masses of matter, the attractions which they will exert upon any bodies placed at equal distances from their centres of gravity will be in the exact proportion of the quantities of ponderable matter composing them.

But it will be convenient to obtain the relation between the masses and the attractions they exert at unequal distances. For this purpose, let the attractions which they exert at equal distances be expressed by f and f', and let the common distance at which those attractions are exerted be expressed by x, and let F and F' express the attractions which they respectively exert at any other distances, r and r', and we shall have, according to the general law of gravitation,

$$f : F :: \frac{1}{x^2} : \frac{1}{r^2}$$

$$f' : F' :: \frac{1}{x^2} : \frac{1}{r'^2},$$

and consequently

$$\frac{f}{F} \times \frac{1}{r^2} = \frac{f'}{F'} \times \frac{1}{r'^2},$$

from which it follows that

$$\frac{f}{f'} = \frac{F \times r}{F' \times r'^2}.$$

But since the masses M and M' are proportional to the attractions f and f', we have

$$\frac{f}{f'} = \frac{M}{M'},$$

and therefore

$$\frac{M}{M'} = \frac{F \times r^2}{F \times r'^2},$$

that is, the attracting masses are proportional to the products obtained, by multiplying any two forces exerted by them by the squares of the distances at which such forces are exerted.

Hence, in all cases in which the attractive forces, exerted by any central masses at given distances, can be measured by any known or observable motions, or other mechanical effects, the proportion of the attracting masses can be determined.

761. **Estimation of central masses around which bodies revolve.** — If bodies revolve around central attracting masses as the planets revolve around the sun, and the satellites around their primaries, the ratio of the attracting forces, and therefore that of the central masses, can be deduced from the periods and distances of the revolving bodies.

Thus if P and P' be the periods of two bodies revolving around different attracting masses, M and M', at the distances r and r', we shall have

$$\frac{F}{F'}=\frac{r}{P^2}\times\frac{P'^2}{r'}=\frac{r}{r'}\times\frac{P'^2}{P^2};$$

and substituting this for $\frac{F}{F'}$ in the formula found in (760), we have

$$\frac{M}{M'}=\frac{r^3}{r'^3}\times\frac{P'^2}{P^2}.$$

By this principle the ratio of the attracting masses can always be ascertained when the periods of any bodies revolving around them at known distances are determined.

762. **Determination of the ratio of the masses of all planets which have satellites, to the mass of the sun.**—This problem is nothing more than a particular application of the principle explained above.

To solve it it is only necessary to ascertain the period and distance of the planet and the satellite, and substitute them in the formula determined in (761). The arithmetical operations being executed, the ratio of the masses will be determined.

763. **To determine the ratio of the mass of the earth to that of the sun.**—Since the earth has a satellite, this problem will be solved by the method given in (762).

If r and r' express the distances of the earth from the sun and moon, and P and P' the periods of the earth and moon, we shall have

$$\frac{r}{r'}=383 \qquad \frac{P'}{P}=\frac{27{\cdot}30}{365{\cdot}25}=\frac{1}{13{\cdot}38}$$

$$\frac{r^3}{r'^3}=56181887 \qquad \frac{P'^2}{P^2}=\frac{1}{179{\cdot}024},$$

which being substituted, and the operations executed, gives

$$\frac{M}{M'}=313823.$$

This quantity, as showing the ratio of the mass of the earth to that of the sun, is not strictly the true amount, but is sufficiently close as an illustration of the method. The true fraction, the sun being unity, is $\frac{1}{315000}$.

764. **Masses of planets.**—The masses of the planets in

relation to the sun being ascertained by the various methods explained in (760), *et seq.*, and the ratio of that of the sun to the earth being in the proportion of 315,000 to 1, let Δ''' express the mass related to that of the earth, and Σ''' to that of the sun as the unit. We shall then have

$$\Delta''' = \frac{\Sigma'''}{315000}.$$

By which Δ''' may be inferred from Σ'''.

The actual weight of the earth in trillions of tons may be easily computed. Having ascertained the linear dimensions and the mean density of the earth, it is a question of mere arithmetical labour to compute its volume and weight. The uncertainty attending the determinations of the mean density of the earth, however, will prevent any very accurate result. For example, the mean density found by Mr. Baily was 5·67 times that of water, while that resulting from the Harton experiments was 6·57 times greater than that of water. For us it will be sufficient to adopt the former value, which is used generally in the calculations of density in various parts of this volume.

Taking the dimensions of the earth at a little less than 8000 miles in diameter, its volume contains about

259,800 millions of cubic miles, or
38,242,027,930 billions of cubic feet.

The average weight of each cubic foot of the earth being 5·67 times greater than the weight of a cubic foot of water, which is found to be equal to 1000 ounces or 62·5 lbs. (H. 71), is, therefore, 354·375 lbs., or 0·1587 of a ton. It follows, consequently, that the total weight of the earth amounts to

6,069,009,832 billions, or
6,069 trillions of tons.

Let the actual weight of the earth in trillions of tons be therefore 6069, and let the weight of any other mass in trillions of tons be δ''', we shall have

$$\delta''' = \Delta''' \times 6069.$$

765. **The densities.**—The mean densities being the quotients obtained by dividing the volumes by the masses, and adopting the mean density of the earth related to that of water as determined by Mr. Baily, the unit being 5·67 (80), let the mean density of any of

the other bodies related to that of the earth as the unit be x, and related to water x', and we shall have

$$x=\frac{\Delta'''}{\Delta''} \qquad x'=x\times 5{\cdot}67.$$

It is evident, however, that if the value 6·57 resulting from the experiments made in the Hartön Colliery, under the superintendance of the Astronomer Royal, were used, considerable differences would be shown in the used mean densities, in relation to that of water, of all the bodies of the solar system. It is only an example of the difficulty of obtaining accurate data, let the experiments be conducted in the most careful and unobjectionable manner. Both values are considered trustworthy, so far as the details of the different methods will allow, no preference can, therefore, be given to either one or other of these determinations. However, as that resulting from the Cavendish experiment of Mr. Baily has generally been used in the comparison of the different densities of the planets, we have adopted it, as already explained, in various parts of this volume.

766. **Certain data not exactly ascertained.**—It will be useful, therefore, to observe that in the determination of several of these data, the results of the observations and computations of astronomers are to a certain extent at variance, and a corresponding uncertainty attends such data, as well as all conditions which depend on them or are derived by calculation from them, as previously explained respecting the densities of planets. This is more especially the case, however, with the masses of those planets which are unaccompanied by satellites, and consequently with the densities which are ascertained by dividing the masses by the volumes.

767. **Example of the masses and densities of some planets.**—As an example of the character and extent of these discrepancies, we give the following estimates of the masses of some of the principal planets expressed as fractions of the mass of the sun; the column A contains the values published in the *Annuaire du Bureau des Longitudes*; the column E contains the values assigned by Professor Encke, from a comparison of all the authorities, except that of Neptune, which is given on the authority of Professor Pierce, who has devoted considerable attention to the theoretical investigations of the motion of this planet; and the columns L and M the values given in the treatises lately published in Germany by Professors Littrow and Mädler.

	A.	E.	L.	M.
MERCURY -	$\frac{1}{2025810}$	$\frac{1}{4865751}$	$\frac{1}{2025810}$	$\frac{1}{4870333}$
VENUS - -	$\frac{1}{401847}$	$\frac{1}{401839}$	$\frac{1}{405871}$	$\frac{1}{401718}$
EARTH - -	$\frac{1}{354936}$	$\frac{1}{389551}$	$\frac{1}{355000}$	$\frac{1}{355499}$
MARS - -	$\frac{1}{2680337}$	$\frac{1}{2680337}$	$\frac{1}{2546320}$	$\frac{1}{2680500}$
URANUS - -	$\frac{1}{24000}$	$\frac{1}{24905}$	$\frac{1}{21000}$	$\frac{1}{24516}$
NEPTUNE -	$\frac{1}{14446}$	$\frac{1}{18780}$	$\frac{1}{19000}$	$\frac{1}{14455}$

It will be observed that in Tables III. IV. and V., the quantities are in all cases reduced to, and expressed in, those actual standard measures and weights with which all persons are familiar. The utility of this was very forcibly expressed and very happily illustrated by the Astronomer Royal, in the popular lectures delivered by him at Ipswich in March, 1848.

768. **Intensity of solar light and heat.**—Since the intensity of solar radiation decreases as the square of the distance from the sun decreases, if γ expresses its intensity at the mean distance of any planet relative to its intensity at the earth, as the unit, we shall have

$$\gamma=\frac{1}{a^2}.$$

769. **Superficial gravity.**—The superficial gravity of a spherical body being in proportion to its mass, divided by the square of its semi-diameter, and the height through which a body falls upon the surface of the earth in one second being 16·095 feet, let g' express the superficial gravity of a spherical body related to that of the earth as the unit, and let f' express the height through which a body submitted to it would fall in one second, and we shall have

$$g'=\frac{\Delta'''}{\Delta^2}, \quad f'=g'\times 16{\cdot}095.$$

770. **Orbital velocities.**—It is easy to show that it follows as a necessary consequence of the harmonic law, which is explained in a subsequent part of this chapter, that the mean orbital velocities of the planets are in the inverse ratio one to another of the square roots of the distances; for since these velocities are proportional to the circumferences, or, what is the same, the semi-diameters

of the orbits, divided by the periods, they are proportional to $\frac{a}{\text{P}}$; but since, by the harmonic law, P^2 is proportional to a^3, the velocities will be proportional to $\frac{a}{\sqrt{a^3}}$, or, what is the same, to $\frac{1}{\sqrt{a}}$ that is, inversely proportional to the square roots of the mean distances.

This being understood, and the mean orbital velocity of the earth expressed in miles per hour being 65,533, let V be the mean velocity of a planet related to that of the earth as the unit, and V′ its mean velocity in miles per hour, and we shall have

$$\text{V} = \frac{1}{\sqrt{a}}, \quad \text{V}' = \text{V} \times 65533.$$

and since the ratio of miles per hour to feet per second is that of 5280 to 3600, if V″ be the velocity in feet per second, we shall have

$$\text{V}'' = \frac{528}{360} \times \text{V}'.$$

771. **Superficial velocity of rotation.** — The superficial velocity of a planet at its equator in virtue of its diurnal rotation is found by comparing the circumference of its equator with the time of its rotation. By the elementary principles of geometry, the circumference of a circle whose diameter is δ, is $\delta \times 3{\cdot}1416$, and if T express the time of rotation in hours, we shall have for v, the velocity of rotation in miles per hour

$$v = \frac{\delta \times 3{\cdot}1416}{\text{T}};$$

which may be reduced to feet per second, as before, by

$$v' = v \times \frac{528}{360}.$$

772. **Solar gravitation.** — The general law of gravitation supplies easy and simple means by which the force of the sun's attraction at the mean distance of each of the planets may be brought into immediate comparison with the known force of gravity at the surface of the earth.

Let this latter force be expressed by g. It will decrease in the same ratio as the square of the distance of the body affected by it increases. The distance of the sun being 23,070 semi-diameters of the earth, the intensity of the attraction which the earth's mass would exert at that distance would be

$$\frac{g}{23070 \times 23070} = \frac{g}{532,224,900}.$$

But the mass of the sun being 315,000 times that of the earth, it will at the same distance exert an attraction 315,000 times greater. The intensity of the attraction, therefore, which the sun exerts at the earth's mean distance will be

$$g \times \frac{315000}{23070^2} = \frac{g}{1690};$$

and the intensity of its attraction at the mean distance of the other planets being still inversely as the squares of the distances, will be found by dividing this by a^2. So that if G express this attraction, and F the height, in thousandths of an inch, through which a body placed at each distance would fall in one second, we shall have

$$G = \frac{g}{1690a^2}, \qquad F = 16095 \times 12 \times G = 193140.$$

By the numbers given in the column G, it is there to be understood that a mass of matter which, placed upon the surface of the earth, would weigh the number of pounds expressed by the denominators of the fractions severally, would, if submitted only to the sun's attraction at the respective mean distances of the planets, gravitate to the sun with the force of one pound. Thus, a mass which on the earth's surface would weigh 1690 lbs., would weigh only one pound if exposed to the sun's attraction in the absence of the earth. In like manner, a mass which upon the earth's surface would weigh 1,524,652 lbs., or 680 tons, would, if exposed to the sun's attraction at the mean distance of Neptune, weigh only one pound, so extremely is the intensity of solar attraction enfeebled by the enormous increase of distance. (Table V.)

The numbers given in the column F have a more absolute sense, and express in thousandths of an inch the actual spaces through which a body would be drawn in one second of time by the sun's attraction at the mean distances of the planets severally.

773. **Calculation of the central force of gravity by the velocity and curvature of a body.**—The space through which any central attraction would draw a body in a given time can be easily calculated, if the body in question moves in a circular, or nearly circular, orbit around such a centre, as all the planets and satellites do.

Let E, *fig.* 104, be the centre of attraction, and E m the distance or radius vector. Let $m\ m' = $ V, the linear velocity. Let $m\ n'$ and

$n\,m'$ be drawn at right angles to E m, and therefore parallel to each other. The velocity $m\,m'$ may be considered as compounded of two forces (M. 169), one in the direction $m\,n'$ of the tangent, and the other $m\,n$ directed towards the centre of attraction E. Now if the body were deprived of its tangential motion $m\,n'$, it would be attracted towards the centre E, through the space $m\,n$, in the unit of time. By means of this space, therefore, the force which the central attraction exerts at m can be brought into direct comparison with the force which terrestrial gravity exerts at the surface of the earth.

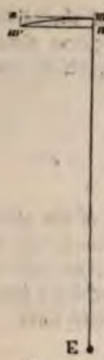

Fig. 104.

It follows, therefore, that if f express the space through which such a body would be drawn in the unit of time, falling freely towards the centre of attraction, we shall have $f = m\,n$. But by the elementary principles of geometry,

$$m\,n \times 2\,\mathrm{E}\,m = m\,m'^2.$$

Therefore,

$$f = \frac{\mathrm{v}^2}{2r};$$

that is, the space through which a body would be drawn towards the centre of attraction, if deprived of its orbital motion, in the unit of time, is found by dividing the square of the linear orbital velocity by twice its distance from the centre of attraction.

Since $\mathrm{v} = \frac{r \times a}{206265}$ we shall also have

$$f = \frac{r \times a^2}{2 \times 206265}.$$

The attractive force, or, what is the same, the space through which the revolving body would be drawn towards the centre in the unit of time, can, therefore, be always computed by these formulæ, when its distance from the centre of attraction and its linear or angular velocity are known.

Since

$$a = \frac{1296000}{\mathrm{P}},$$

which being substituted for a in the preceding formula, will give

$$f = 412541 \times \frac{r}{\mathrm{P}^2};$$

by which the attractive force may always be calculated when the distance and period of the revolving body are known.

774. **Law of gravitation shown in the case of the moon.**—The attraction exerted by the earth, at its surface, may be compared with the attraction it exerts on the moon by these formulæ.

In the case of the moon $v = 0{\cdot}6356$ miles, and $r = 239{,}000$ miles, and by calculations from these data, we find

$$f = 0{\cdot}0000008459^{\text{miles}} = 0{\cdot}0536^{\text{inch.}}$$

The attraction exerted by the earth at the moon's distance would, therefore, cause a body to fall through 536 ten-thousandths of an inch, while at the earth's surface it would fall through 193 inches (M 245).

The intensity of the earth's attraction on the moon is, therefore, less than its attraction on a body at the surface, in the ratio of 1,930,000 to 536, or 3600 to 1, or, what is the same, as the square of 60 to 1.

But it has been shown that the moon's distance from the earth's centre is 60 times the earth's radius. It appears, therefore, that in this case the attraction of the earth decreases as the square of the distance from the attracting centre increases; and that consequently, the same law of gravitation prevails as in the elliptic orbit of a planet.

775. **Sun's attraction on planets compared—law of gravitation fulfilled.**—In the same manner, exactly, the attractions which the sun exerts at different distances may be computed by the motions and distances of the planets. The distance of a planet gives the circumference of its orbit, and this, compared with its periodic time, will give the arc through which it moves in a day, an hour, or a minute. This, represented by $m\,m'$, *fig.* 104, being known, the space $m\,n$ through which the planet would fall towards the sun in the same time may be calculated, and this being done for any two planets, it will be found that these spaces are in the inverse ratio of the squares of their distances.

Thus, for example, let the earth and Jupiter be compared in this manner. If D express the distance from the sun in miles, P the period in days, A the arc of the orbit in miles described by the planet in an hour, and H the space $m\,n$ in miles, through which the planet would fall towards the sun in an hour if the tangential force were destroyed, we shall then have

	D.	P.	A.	H.
Earth - -	91,500,000	365·26	65,533	24·4020
Jupiter - -	475,700,000	4332·62	28,743	0·9019

Now, on comparing the numbers in the last column with the squares of those in the first column, we find them in almost exact accordance. Thus,

$$(91\tfrac{1}{2})^2 : (475{\cdot}7)^2 :: 24{\cdot}402 : 0{\cdot}9028.$$

The difference, small as it is, would disappear, if exact values were taken instead of round numbers.

776. **The harmonic law.**—A remarkable numerical relation thus denominated, prevails between the periodic times of the planets and their mean distances, or major axes of their orbits. If the squares of the numbers expressing their periods be compared with the cubes of those which express their mean distances, they will be found to be very nearly in the same ratio. They would be exactly so if the masses or weights of the planets were absolutely insignificant compared with that of the sun. But although these masses, as will appear, are comparatively very small, they are sufficiently considerable to affect, in a slight degree, this remarkable and important law.

Omitting for the present, then, this cause of deviation, the harmonic law may be thus expressed. If P, P′, P″, &c., be a series of numbers which express or are proportional to the periodic times, and r, r', r'', &c., to the mean distances of the planets, we shall have

$$\frac{r^3}{P^2}=\frac{r'^3}{P'^2}=\frac{r''^3}{P''^2}, \text{ \&c.};$$

that is, the quotients found by dividing the numbers expressing the cubes of the distances by the numbers which express the squares of the periods are equal, subject nevertheless to such deviations from the law as may be due to the cause above mentioned.

777. **Fulfilled by the planets.—Method of computing the distance of a planet from the sun when its periodic time is known.**—To show the near approach to numerical accuracy with which this remarkable law is fulfilled by the motions of the planets composing the solar system, we have exhibited in the following table the relative approximate numerical values of their several distances and periods, and it is evident on comparing the two columns which give the cubes of the distance, and the squares of

the periods, that the quotients found by dividing the column r^3 by that of P^2 are sensibly equal:—

Name of Planet.	Distance. r	Period. P	Cube of Distance. r^3	Square of Period. P^2
Mercury - -	0·387	0·241	0·057960603	0·058081
Venus - - -	0·723	0·615	0·377933067	0·378225
Earth - - -	1·00	1·00	1·000000000	1·000000
Mars - - -	1·52	1·88	3·511808	3·5344
Planetoids - -	2·50	4·00	15·625000	16·0000
Jupiter - -	5·20	11·86	140·608000	140·6596
Saturn - - -	9·54	29·46	868·250664	870·2500
Uranus - -	19·18	84·01	7055·792632	7057·6801
Neptune - -	30·00	164·62	27000·000000	27099·7444

In general the distance of a planet from the sun can be computed by means of this law, when the distance of the earth and the periodic times of the earth and planet are known.

For this purpose find the number which expresses the periodic time P of the planet, that of the earth being expressed by 1; and let D be the number which expresses the mean distance of the planet from the sun, that of the earth being also expressed by 1. We shall then, according to the harmonic law, have

$$1^2 : P^2 :: 1^3 : D^3$$

from which we obtain

$$P^2 = D^3.$$

To find the distance D, therefore, it is only necessary to find the number whose cube is the square of the number expressing the period, or, what is the same, to extract the cube root of the square of the period.

778. **Harmonic law deduced from the law of gravitation.**— It is not difficult to show that this remarkable law is a necessary consequence of the law of gravitation.

Supposing the orbits of the planets to be circular, which for this purpose they may be taken to be, let the distance, period, and angular velocity of any one planet be expressed by r, P, and a, and those of any other by r' P′ and a', and let the forces with which the sun attracts them respectively be expressed by f and f'. We shall then, according to what has been proved (773), have

$$f = \frac{r \times a^2}{2 \times 206265} \qquad f' = \frac{r' \times a'^2}{2 \times 206265},$$

and therefore

$$f : f' :: r \times a^2 : r' \times a'^2.$$

But by the law of gravitation

$$f : f' :: r'^2 : r^2,$$

therefore

$$r'^2 : r^2 :: r \times a^2 : r' \times a'^2,$$

and consequently

$$r'^3 \times a'^2 = r^3 \times a^2.$$

But the angles described in the unit of time are found by dividir 360° by the periodic times. Therefore,

$$a = \frac{360°}{P} \qquad a' = \frac{360°}{P'}$$

and consequently

$$\frac{r^3}{P^2} = \frac{r'^3}{P'^2},$$

which is, in fact, the harmonic law.

779. **Kepler's laws.**—The three great planetary laws di covered by Kepler, and which are generally known by his nam are 1, the equable description of areas; 2, the elliptic form the orbits; and 3, the harmonic law, which has been explaine above. Kepler deduced them as matter of fact from the recorde observations of himself and other astronomers, but failed to sho the principle by which they were connected with each othe Their interpretation was given by Newton, who showed their cor nection.

We must refer those of our readers who desire an extende theoretical knowledge of the movements of the solar systen including the application of these celebrated laws of Kepler, those special works on the higher branches of astronomy, whic have been prepared solely for the assistance of students of th science. It is not the object of this work to enter fully int questions requiring the use of mathematical analysis for the elucidation, as indeed, the limited space allotted to this volum would not allow us to do; but it has been the endeavour to give general idea of the peculiarities of the various members of th solar system in a plain and popular manner, without disturbing th reader with mathematical symbols in the explanations.

780. **The apparent motion of an inferior planet.**—Befor proceeding to exhibit in a synoptical table the principal element of the various planets composing the solar system, it will be prope in this place to give a simple explanation of the apparent motior of an inferior and a superior planet in reference to the earth. T deduce, therefore, the apparent from the real motion of an inferic

planet, let E, *fig.* 105, be the place of the earth, *s* that of the sun, and *c b c′ e* the orbit of the planet; the direction of the planet's motion being shown by the arrows, the positions which it assumes successively are indicated at *c′*, *a′*, *e*, *a*, *c*, *b*, *e′*, and *b′*. Since the earth moves round the sun in the same direction as the planet, the apparent motion of the sun *s* will be from the left to the right of an observer looking from E at *s*; and since this motion is always from west to east, the planet will be west of the sun when it is anywhere in the semicircle *c b e′ b′ c′*, and east of it when it is anywhere in the semicircle *c′ a′ e a c*.

Fig. 105.

The elongation (272) of the planet, being the angle formed by lines drawn to the sun and planet from the earth, will always be east when the planet is in the semicircle *c′ e c*, and west when in the semicircle *c′ e′ c*.

The planet will have its greatest elongation east when the line E *e* directed to it from the earth is a tangent to its orbit, and in like manner its greatest elongation west when the line E *e′* is a tangent to the orbit.

In these positions the angle *s e* E, or *s e′* E, at the planet is 90°, and consequently the elongation and the angle *e s* E, or *e′ s* E at the sun, taken together, make up 90°.

It appears, therefore, that the greatest elongation of an inferior planet must be less than 90°.

If the earth were stationary the real orbital motion of the planet would give it an apparent motion alternately east and west of the sun, extending to a certain limited distance, resembling the oscillation of a pendulum. While the planet moves from *c′* to *e*, it will appear to depart from the sun eastward, and when it moves from *e* to *c*, it will appear to return to the sun; the elongation in the former case constantly increasing till it attain its maximum eastward, and in the latter constantly decreasing till it become nothing. It is to be observed, that the orbital arc *c′ e* being greater than *e c*, the time of attaining the greatest eastern elongation after superior conjunction is greater than the time of returning to the sun from the greatest elongation to inferior conjunction.

After inferior conjunction, while the planet passes from *c* to *e′*, its elongation constantly increases from nothing at *c* to its maximum

west at e'; and when the planet moves from e' to c', it agai decreases until it becomes nothing at superior conjunction. Sinc the orbital arcs, $c\ e'$ and $e'\ c'$, are respectively equal to $c\ e$ and $c'\ e$ it follows, that the interval from inferior conjunction to the great est elongation west, is equal to the interval from the greatest elon gation east to inferior conjunction. In like manner, the interva from superior conjunction to the greatest elongation east, is equal t the interval from the greatest elongation west to superior conjunction

The oscillation of the planet alternately east and west is there fore made through the same angle—that is, the angle e E e', in cluded by tangents drawn to the planet's orbit from the earth; bu the apparent motion from the greatest elongation west to th greatest elongation east, is slower than the apparent motion fron the greatest elongation east to the greatest elongation west, in th ratio of the length of the orbital arcs $e\ c'\ e'$ to $e\ c\ e'$.

The planet being included within the orbit of the earth, th orbital motion of the earth will give it an apparent motion in th ecliptic, in the same direction as the apparent motion of the sun but, since the apparent motion of a visible object increases as it distance decreases, and *vice versâ*, and since the planet being at considerable distance from the centre of the earth's orbit, th distance of the earth from it is subject to variation, the apparen motion imparted to the planet by the earth's orbital motion, wil be subject to a proportionate variation, being greatest when th planet is in inferior conjunction, and least when in superior con junction.

The apparent motion of the planet, as it is projected upon th firmament by the visual ray, arises from the combined effect of it own orbital motion and that of the earth. Now it is evident, fron what has been just explained, that the effect of the planet's ow motion, is to give it an apparent motion from west to east, whil passing from its greatest elongation west, through superior con junction, to its greatest elongation east, and a contrary apparen motion from east to west, while passing from its greatest elonga tion east, to its greatest elongation west, through inferior con junction.

But since, in all positions, the effect of the orbital motion of th earth, is to give the planet an apparent motion directed from wes to east, both causes combine to impart to it this apparent motion while passing from its western to its eastern elongation, through superior conjunction. On the other hand, the effect of the orbita motion of the planet being an apparent motion from east to west in passing from its eastern to its western elongation, through inferio conjunction, while, on the contrary, the earth's motion imparts to i an apparent motion from west to east, the actual apparent motion

of the planet, resulting from the difference of these effects, will be westward or eastward, according as the effect of the one or the other predominates, and the planet will appear stationary when these opposite effects are equal.

In leaving the greatest eastern elongation, the effect of the earth's motion predominates, and the apparent motion of the planet continues to be, as before, eastward. As, in approaching inferior conjunction, the direction of the planet's motion becomes more and more transverse to the visual line, and the distance of the planet decreases, the effect of the planet's motion increasing becomes, at length, equal to the effect of the earth's motion, and the planet then becomes stationary. This takes place at a certain elongation east. After this, the effect of the planet's motion predominating, the apparent motion becomes westward, and this westward motion continues through inferior conjunction, until the planet acquires a certain elongation west, equal to that at which it previously became stationary. Here, the effects becoming again equal, the planet is again stationary, after which, the effect of the earth's motion predominating, the apparent motion becomes eastward, and continues so to the greatest elongation west, after which, as before, both causes combine in rendering it eastward.

781. **Apparent motion as projected on the ecliptic.**—From what has been explained in the preceding paragraph, the apparent motion of the planet on the firmament will be easily understood. Let A, B, E, F, K., *fig.* 106, represent the ecliptic in which the planet is at present supposed to move. While passing from its western to its eastern elongation, it appears to move in the same direction as the sun, from A towards B. As it approaches B, its apparent motion eastward becomes gradually slower until it stops altogether at B, and becomes for a short interval stationary; it then moves westward, returning upon its course to C, where it again becomes stationary; after which it again moves eastward, and continues to move in that direction till it arrives at a certain point D, where it again becomes stationary; and then, returning upon its course, it again moves westward to E, where it again becomes stationary; after which, it again changes its direction and moves eastward to F, where, after being stationary, it turns westward, and so on.

The middle points of the arcs B C, D E, F G, &c. of retrogression are those at which the planet is in inferior conjunction; and the middle points of the arcs C D, E F, G H, &c. of progression are those at which the planet is in superior conjunction.

782. **Apparent motion of a superior planet.**—To deduce the apparent motion of a superior planet from the real orbital motions of the earth and the planet, let S, *fig.* 107, be the place

of the sun, P that of the planet, and E E′ E‴ E″ the orbit of
earth included within that of the planet, the direction of
motions of the earth and planet being indicated by the arrows.

Fig. 106.

When the earth is at E‴, the sun S and planet P are in the sa
visual line, and the planet is consequently in conjunction. W
the earth moves to e', the elongation of the planet west of the
is S e' P. This elongation increasing as the earth moves in
orbit, becomes 90° at E′, when the visual direction E′ P of
planet is a tangent to the earth's orbit, and the planet is then in
western quadrature.

While the earth continues its orbital motion to e''', the elon
tion west of the sun continues to increase, and at length, wl
the earth comes to the position E, it becomes 180°, and the pla
is in opposition.

After passing E, when the earth moves towards e'', the elon
tion of the planet is east of the sun, and is less than 180°,
greater than 90°. As the earth continues to advance in its or
the elongation decreasing becomes 90° when, at E″, the vis
direction of the planet is a tangent to the earth's orbit.
planet is then in its eastern quadrature.

As the earth moves from E'' to E''', the elongation, being still east, constantly decreases until it becomes nothing at E'', where the planet is in conjunction.

783. **Direct and retrograde motion.** — If the planet were immovable, the effect of the earth's motion would be to give it an oscillatory motion alternately eastward and westward through the angle $E'\,P\,E''$, which the earth's orbit subtends at the planet. While the earth moves from E'' through E''' to E', the planet would appear to move *eastward* through the angle $E'\,P\,E''$, and while the earth moves from E' through E to E'', it would appear to move *westward* through the same angle.

Fig. 107.

Thus the effect of the earth's motion alone is to make the planet appear to move from east to west, and from west to east alternately, through a certain arc of the ecliptic, the length of which will depend on the relation between the distances of the earth and planet from the sun, the arc being, in fact, measured by the angle which the earth's orbit subtends at the planet, and, consequently, this angle of apparent oscillation will decrease in the same ratio as the distance of the planet increases.

The times in which the two oscillations eastward and westward would be made are not equal, the time from the western to the eastern quadrature being less than the time from the eastern to the western quadrature, in the ratio of the orbital arc $E'\,E\,E''$ to the arc $E''\,E'''\,E'$.

It is evident, therefore, that the more distant the planet P is, the less unequal will be these arcs, and consequently the less unequal will the intervals be between quadrature and quadrature.

But, meanwhile, the earth being included within the orbit of the planet, the effect of the planet's orbital motion will be to give it an apparent motion in the ecliptic, always in the same direction in which the sun would move when in the same place, and therefore always eastward or direct.

This apparent motion, though always direct, is not uniform, since it increases in the same ratio as the distance of the earth from the planet decreases, and *vice versâ*. This apparent motion thus due to the planet's own orbital motion, is therefore greater

from western to eastern quadrature, than from eastern to western quadrature.

From eastern to western quadrature, through conjunction, the apparent motion of the planet is direct, because both its own orbital motion and that of the earth combine to render it so. From western quadrature, as the planet approaches opposition, the effect of the earth's motion is to render the planet retrograde, while the effect of its own motion is to render it direct. On leaving quadrature the latter effect predominates, and the apparent motion is direct; but at a certain elongation before arriving at opposition, the effect of the earth's motion increasing, becomes equal to that of the planet, and, neutralising it, renders the planet stationary; after which, the effect of the earth's motion predominating, the planet becomes retrograde, and continues so until it acquires an equal elongation east, when it again becomes stationary, and is afterwards direct, and continues so.

784. **Apparent motion as projected on the ecliptic.**—Let A, *fig.* 106, represent the place of a superior planet when moving from its western quadrature towards conjunction, its apparent motion being then direct. Let B be the point where it becomes stationary after its eastern quadrature; its apparent motion then becoming retrograde, it appears to return upon its course and moves westward to C, where it again becomes stationary; after which it again returns on its course and moves direct or eastward, and continues so until it arrives at a certain point D, after its western quadrature, when it again becomes stationary, and then again retrogrades, moving through the arc D E, which will be equal to B C; after which it will again become direct, and so on.

The places of the planet's opposition are the middle points of the arcs of retrogression B C, D E, F G, &c.; and the places of conjunction are the middle points of the arcs of progression C D, E F, G H, &c.

It is evident from the preceding explanation, therefore, that the apparent motion of a superior planet projected on the ecliptic is in all respects similar to that of an inferior planet, the difference being, that in the latter the middle point of the arc of retrogression corresponds to inferior conjunction, while in the former it corresponds to opposition.

It will be apparent, from what has been shown, that the angle which the earth gains upon the planet in the interval between its western and eastern quadratures, is the angle which the earth's orbit subtends at the planet, or twice the annual parallax of the planet (165).

Though not bearing immediately on the subject of this paragraph, it will not be entirely out of place to explain here the daily synodic motion of a planet. The daily synodic motion is the angle by

which the planet departs from or approaches to the earth in its course around the sun. Thus if A express in degrees the angle formed by two lines drawn from the sun, one to the planet and the other to the earth, the daily synodic motion will be the daily increase or decrease of A produced by the motions of the earth and planet. For, since the earth and planet both move in the same direction around the sun, with different angular motions, the increase or decrease of A will be the difference of their motions.

785. **Synoptic table of the principal elements of the planetary orbits.** — In Table I. are given the elements of the planetary orbits as referred to the epoch specially assigned for each planet. Those of the more recently discovered planetoids must be regarded somewhat provisionally, and probably will be corrected when their positions have been more accurately determined by observation. In the majority, however, the elements as given in the Table have been determined with considerable accuracy by the several authorities whose names are mentioned in the last column, and are the most recent determinations.

The value of the solar equatorial horizontal parallax, or the angle which the earth's semi-diameter at mean distance subtends at the sun, adopted in the computation of the distances of the planets from the sun and earth in Table II., has been assumed to be $8''\cdot94$. These numbers have been finally agreed upon by the Astronomer Royal and M. Le Verrier, until a more accurate determination is made at future favourable oppositions of Mars, or at the next transits of Venus in 1874 and 1882. An abstract of the investigations from which this value has been obtained will be found in the Appendix (807).

The planets in the following table are arranged in the order of distance from the sun, the elements of the orbit of each planet being inserted as follows: —

1. The mean diurnal heliocentric motion.
2. The sidereal period.
3. The mean distance from the sun, or semi-axis of orbit, that of the earth being unity.
4. The excentricity of the orbit.
5. The longitude of the perihelion, referred to the mean equinox of the respective epochs.
6. The mean longitude at epoch.
7. The longitude of the ascending node, referred to the mean equinox of the respective epochs.
8. The inclination of the planet's orbit to the plane of the ecliptic.
9. The epoch or date at which the elements of the orbits have been assigned.

TA

PRINCIPAL ELEMENT

Name of Planet.	Planet's Symbol.	Mean diurnal Heliocentric Motion.	Sidereal Period.	Mean distance from Sun, or Semi-axis.—(Earth's distance=1.)	Excentricity.	Mean Lo at Ep
		"	days.			°
MERCURY - -	☿	14732·419	87·9693	0·387099	0·205618	327 15
VENUS - - -	♀	5767·668	224·7008	0·723332	0·006833	245 33
EARTH - - -	⊕	3548·193	365·2564	1·000000	0·016771	100 46
MARS - - -	♂	1886·518	686·9797	1·523691	0·093262	83 40
FLORA - - -	8	1086·331	1193·01	2·201387	0·156704	68 48
ARIADNE - -	43	1084·937	1194·54	2·203273	0·167523	102 42
FERONIA - -	72	1040·147	1245·98	2·266077	0·119780	339 12
HARMONIA -	40	1039·335	1246·95	2·267253	0·046591	187 42
MELPOMENE -	18	1020·120	1270·44	2·295636	0·217671	95 10
SAPPHO - -	80	1019·680	1270·99	2·296299	0·200250	45 16
VICTORIA - -	12	994·835	1302·73	2·334204	0·218923	7 42
EUTERPE - -	27	986·990	1313·08	2·346729	0·173215	236 42
VESTA - - -	4	977·830	1325·38	2·373363	0·089811	326 21
URANIA - -	30	975·274	1328·86	2·365485	0·126518	338 1
NEMAUSA - -	51	975·138	1329·04	2·365703	0·066181	131 31
CLIO - - -	84	974·056	1330·52	2·367457	0·237576	353 2
IRIS - - -	7	962·581	1346·38	2·386234	0·230853	207 30
METIS - - -	9	962·339	1346·72	2·386633	0·123324	128 8
ECHO - - -	60	958·474	1352·15	2·393045	0·184741	164 18
AUSONIA - -	63	957·320	1353·78	2·394997	0·125840	216 56
PHOCEA - -	25	953·823	1358·74	2·400822	0·254313	22 7
MASSILIA - -	20	948·559	1366·28	2·409695	0·143552	260 13
ASIA - - -	67	941·491	1376·54	2·421737	0·185088	242 10
NYSA - - -	44	941·360	1376·73	2·421962	0·150771	35 27
HEBE - - -	6	939·082	1380·07	2·425877	0·202668	298 23
BEATRIX - -	83	937·415	1382·53	2·428751	0·084155	205 30
LUTETIA - -	21	933·554	1388·24	2·435443	0·162104	41 23
ISIS - - - -	42	930·906	1392·19	2·440061	0·225615	247 30

THE PLANETARY ORBITS.

Longitude of Perihelion.	Longitude of Ascending Node.	Inclination of Orbit.	Mean Solar Time of Epoch at Greenwich, Paris, Berlin, or Washington.	Authority for Elements.	Planet's Symbol.
° ′ ″	° ′ ″	° ′ ″			
75 7 0·0	46 33 3·3	7 0 8·2	1850 Jan. 1·0 P.	Annales de	☿
129 23 56·0	75 19 4·2	3 23 30·8	" "	l'Observatoire	♀
100 21 40·0	0 0 0·0	0 0 0·0	" "	Impérial de	⊕
333 17 50·5	48 22 44·8	1 51 5·1	" "	Paris. Tome II.	♂
32 54 28·3	110 17 48·6	5 53 8·0	1848 Jan. 1·0 B.	Brünnow.	(8)
277 48 9·6	264 37 43·9	3 27 40·5	1866 Jan. 1·0 B.	Weiss.	(43)
307 54 49·5	207 44 59·6	5 23 54·5	1866 Jan. 0·0 B.	C. H. F. Peters.	(72)
0 54 7·0	93 34 54·2	4 15 48·4	1863 Jan. 0·0 B.	Schubert.	(40)
15 5 31·0	150 3 49·7	10 9 16·9	1854 Jan. 0·0 B.	Schubert.	(18)
355 5 12·5	218 31 45·0	8 36 51·3	1865 Oct. 7·0 B.	Tietjen.	(80)
301 39 25·0	235 34 41·7	8 23 17·7	1851 Jan. 0·0 B.	Brünnow.	(12)
87 35 3·6	93 48 1·5	1 35 29·8	1866 May 26·5 B.	Günther.	(27)
250 28 1·2	103 24 59·1	7 7 58·1	1866 Aug. 27·0 G.	Farley.	(4)
31 28 57·9	308 9 39·2	2 6 6·9	1865 Aug. 18·0 B.	Günther.	(30)
174 52 0·6	175 43 6·3	9 56 52·8	1865 Jan. 17·0 B.	Tietjen.	(51)
339 25 43·1	327 20 56·7	9 22 28·5	1865 Nov. 10·0 B.	Valentiner.	(84)
41 23 21·1	259 47 55·8	5 28 3·0	1850 Jan. 0·0 B.	Brünnow.	(7)
71 3 52·1	68 31 35·2	5 36 0·3	1858 June 30·0 B.	Lesser.	(9)
98 33 32·6	192 2 9·0	3 34 18·5	1866 Jan. 0·0 B.	C. H. F. Peters.	(60)
269 32 49·0	338 6 58·3	5 47 16·3	1865 April 17·0 B.	Tietjen.	(63)
302 49 53·4	214 5 7·3	21 34 36·3	1865 Nov. 12·0 B.	Günther.	(25)
98 29 31·8	206 45 6·7	0 41 9·5	1866 June 15·5 B.	Günther.	(20)
306 8 6·9	202 43 29·0	5 59 35·9	1865 Jan. 7·0 B.	Frischauf.	(67)
112 5 31·5	131 3 31·2	3 41 57·6	1866 Oct. 9·0 B.	Powalky.	(44)
15 6 12·7	138 39 17·3	14 46 43·9	1866 June 30·0 B.	R. Luther.	(6)
188 28 20·9	27 34 9·1	5 2 11·3	1865 May 4·0 B.	Becker.	(82)
327 3 8·4	80 27 7·2	3 5 9·5	1853 Jan. 2·0 B.	Lesser.	(21)
318 0 48·7	84 30 40·4	8 34 33·0	1860 Jan. 0·0 B.	Brunn.	(49)

TABLE

Name of Planet.	Planet's Symbol.	Mean diurnal Heliocentric Motion.	Sidereal Period.	Mean distance from Sun, or Semi-axis.—(Earth's distance=1.)	Excentricity.	Mean Longitude at Epoch.
		″	days.			° ′ ″
FORTUNA - -	(19)	930·279	[illegible]	2·441157	0·158590	289 12 57·
EURYNOME -	(79)	929·129	1394·8	·443172	0·195058	45 48 54·
PARTHENOPE -	(11)	924·154	1402·[illegible]	·451936	0·099581	196 28 46·
THETIS - - -	(17)	912·066	1420·[illegible]	·473545	0·127701	77 41 41·
HESTIA - -	(46)	883·564	1466·7[illegible]	·526460	0·164166	316 22 21·
	(89)	871·444	1487·19	·549835	0·180304	330 44 23·
AMPHITRITE -	(29)	869·334	14[illegible]	·553959	0·073989	161 17 34·
EGERIA - -	(13)	857·880	15[illegible]	·576641	0·087093	340 59 56·
ASTRÆA - -	(5)	857·612	1511·15	·577175	0·187521	5 21 27·
IRENE - - -	(14)	853·208	1518·97	2·586035	0·166022	314 47 16·
POMONA - -	(32)	852·588	1520·08	2·587289	0·083017	57 16 27·
MELETE - -	(56)	848·330	1527·71	2·595938	0·237448	278 9 37·
PANOPEA - -	(70)	839·906	1543·03	2·613268	0·183129	248 44 41·
CALYPSO - -	(53)	836·805	1548·75	2·619715	0·203902	100 5 14·
DIANA - - -	(78)	835·353	1551·44	2·622755	0·205514	18 3 38·
THALIA - -	(23)	833·293	1555·28	2·627079	0·232029	226 51 20·
FIDES - - -	(37)	826·545	1567·97	2·641356	0·176732	333 6 46·
EUNOMIA - -	(15)	825·455	1570·04	2·643681	0·187249	149 57 32·
VIRGINIA - -	(50)	822·944	1574·83	2·649054	0·286908	93 20 40·
MAIA - - -	(66)	821·921	1576·79	2·651252	0·158095	131 32 3·
IO - - - -	(85)	820·836	1578·88	2·653588	0·190656	8 41 54·
PROSERPINE -	(26)	819·685	1581·10	2·656072	0·087336	227 31 10·
CLYTIE - -	(73)	814·843	1590·49	2·666582	0·042750	25 18 6·
JUNO - - -	(3)	814·007	1592·12	2·668409	0·257250	10 2 22·
EURYDICE - -	(75)	813·365	1593·38	2·669812	0·306906	261 52 38·
FRIGGA - -	(77)	812·401	1595·27	2·671924	0·135814	286 47 48·
ANGELINA - -	(64)	808·311	1603·34	2·680929	0·128193	119 20 12·
CIRCE - - -	(34)	805·855	1608·23	2·686373	0·107344	320 16 21·
CONCORDIA -	(58)	799·631	1620·75	2·700295	0·042531	210 32 53·
ALEXANDRA -	(54)	794·322	1631·58	2·712315	0·196916	19 4 16·

Continued.

Longitude of Perihelion.	Longitude of Ascending Node.	Inclination of Orbit.	Mean Solar Time of Epoch at Greenwich, Paris, Berlin, or Washington.	Authority for Elements.	Planet's Symbol.
° ′ ″	° ′ ″	° ′ ″			
30 57 54·2	211 22 29·1	1 32 44·8	1863 June 24·0 B.	Powalky.	19
44 17 58·1	206 42 42·6	4 36 46·5	1864 Jan. 1·0 B.	Tischler.	79
317 14 31·4	125 7 27·9	4 37 1·6	1865 Mar. 27·0 B.	R. Luther.	11
260 24 17·6	125 23 4·2	5 36 6·2	1866 July 1·5 B.	Schönfeld.	17
354 10 34·9	181 26 45·3	2 17 32·1	1865 July 26·0 B.	Karlinski.	46
353 16 34·7	311 29 37·5	16 11 25·3	1866 Sept. 0·0 B.	Knorre.	59
56 56 1·8	356 30 5·2	6 7 49·3	1866 Mar. 10·0 B.	Günther.	29
120 5 15·0	43 15 56·3	16 30 48·8	1866 Aug. 29·0 B.	Günther.	13
135 14 56·7	141 26 16·1	5 19 9·0	1865 Sept. 1·0 G.	Farley.	5
179 52 6·8	86 42 23·7	9 7 37·5	1864 Nov. 28·0 B.	Bruhns.	14
193 21 49·8	220 42 55·6	5 28 49·9	1855 Jan. 5·0 B.	Lesser.	32
293 29 25·0	194 27 23·7	8 1 40·9	1865 June 20·0 B.	R. Luther.	56
300 3 30·3	48 14 42·6	11 38 30·2	1861 May 28·0 B.	Dunér.	70
92 53 30·3	144 1 9·0	5 6 39·0	1866 Jan. 4·0 B.	Günther.	53
121 42 47·5	333 55 48·4	8 38 39·9	1865 Oct. 4·0 B.	Tietjen.	78
123 48 52·3	67 41 4·2	10 13 28·2	1867 May 30·0 W.	Schubert.	23
66 20 17·3	8 12 29·4	3 7 12·3	1853 Oct. 5·0 B.	Tiele.	37
27 52 0·5	293 52 14·5	11 44 17·4	1854 Jan. 0·0 B.	Schubert.	15
9 53 21·4	173 31 59·2	2 47 48·4	1863 Jan. 18·0 B.	Powalky.	50
44 25 0·6	8 15 23·7	3 4 15·1	1865 Jan. 27·0 B.	Weiss.	66
322 37 1·8	203 51 47·2	11 53 16·5	1865 Nov. 14·0 G.	Dolman.	85
236 25 15·0	45 54 59·3	3 35 47·7	1853 June 11·0 B.	Hoek.	26
59 59 11·0	7 34 19·1	2 24 39·5	1864 Oct. 4·0 B.	Oppolzer.	73
54 56 11·0	170 49 32·9	13 1 20·7	1865 Sept. 1·0 G.	Hind.	3
334 20 56·8	359 57 6·0	5 0 2·7	1865 Dec. 13·0 B.	Engelmann.	75
58 11 32·0	2 9 27·6	2 27 56·6	1866 Jan. 0·0 B.	C. H. F. Peters.	77
123 33 10·6	311 4 48·7	1 19 51·8	1865 Jan. 7·0 B.	Oppolzer.	64
150 3 19·2	184 48 36·5	5 26 28·9	1865 Aug. 20·0 B.	Auwers.	34
188 41 55·0	161 19 35·6	5 1 53·2	1865 Jan. 7·0 B.	Oppolzer.	58
295 27 8·7	314 5 8·4	11 46 41·9	1863 Nov. 14·0 B.	Schultz.	31

TABLE I. Con

me of Planet.	Planet's Symbol.	Mean diurnal Heliocentric Motion.	Sidereal Period.	Mean distance from Sun, or Semi-axis.—(Earth's distance = 1.)	Excentricity.	Mean Longitude at Epoch.			Lon Pe
		"	days.			°	′	″	°
YMPIA - -	(59)	793·977	1632·29	2·713100	0·117263	352	33	27·7	18
GENIA - -	(45)	790·432	1639·61	2·721209	0·079920	250	12	36·5	23(
DA - - -	(38)	782·250	1656·76	2·740148	0·155432	112	58	27·6	10(
ALANTA -	(36)	779·694	1662·19	2·746129	0·301229	117	40	26·0	4
OBE - - -	(71)	775·733	1670·68	2·755474	0·173720	145	15	14·4	22
NDORA - -	(55)	774·218	1673·95	2·759068	0·144736	46	51	59·5	1
CMENE - -	(82)	773·711	1675·04	2·760273	0·226005	103	51	42·6	13
RES - - -	(1)	771·021	1680·88	2·766692	0·080264	125	58	25·7	14
ETITIA - -	(39)	770·857	1681·25	2·767081	0·114659	234	9	32·1	
PHNE - -	(41)	769·997	1683·12	2·769147	0·265929	275	57	31·6	22
LLAS - -	(2)	769·805	1683·54	2·769601	0·239966	94	51	32·0	12
ISBE - -	(88)	769·561	1684·08	2·770186	0·165027	305	0	1·9	30
LATEA - -	(74)	766·439	1690·93	2·777705	0·238200	256	45	22·3	
LLONA - -	(28)	766·122	1691·64	2·778470	0·150099	66	3	57·4	12
TO - - -	(68)	765·323	1693·40	2·780405	0·188461	78	58	20·6	34
RPSICHORE -	(81)	735·024	1763·21	2·856296	0·211758	21	59	26·0	4
LYHYMNIA -	(33)	732·029	1770·42	2·864085	0·339119	210	17	46·0	34
LAIA - -	(47)	725·499	1786·36	2·881244	0·132044	116	33	25·5	31
LLIOPE - -	(22)	714·514	1813·82	2·910711	0·098541	347	53	23·0	5
YCHE - -	(16)	709·760	1825·97	2·923681	0·135429	130	37	13·6	1
SPERIA - -	(69)	692·630	1871·13	2·971693	0·173831	163	53	22·3	1(
NAË - - -	(61)	688·082	1883·50	2·984773	0·161600	327	20	9·7	34
UCOTHEA -	(35)	680·588	1904·24	3·006638	0·217211	333	34	42·4	2(
LES - - -	(49)	655·621	1976·75	3·082494	0·237207	52	15	20·5	3
MELE - -	(86)	652·985	1984·73	3·090786	0·204954	37	2	18·5	2
ROPA - -	(52)	650·088	1994·04	3·099942	0·101415	136	21	22·1	10
RIS - - -	(48)	647·130	2002·69	3·109402	0·076636	309	32	10·2	74
TIOPE - -	(90)	644·196	2011·81	3·118839	0·147672	283	32	58·7	243
ATO - -	(62)	640·859	2022·29	3·129653	0·169657	313	48	49·9	34
EMIS - -	(24)	636·763	2035·29	3·143057	0·116925	180	22	27·3	140

Continued.

Longitude of Perihelion.	Longitude of Ascending Node.	Inclination of Orbit.	Mean Solar Time of Epoch at Greenwich, Paris, Berlin, or Washington.	Authority for Elements.	Planet's Symbol.
° ′ ″	° ′ ″	° ′ ″			
18 14 34·5	170 16 17·3	8 37 16·3	1865 Jan. 7·0 B.	Oppolzer.	(59)
230 50 34·9	148 6 3·7	6 35 25·0	1866 June 4·0 B.	Löwy.	(45)
100 51 44·3	296 27 34·9	6 58 25·3	1856 Jan. 0·0 B.	Allé.	(38)
42 47 47·7	359 11 14·9	18 42 14·8	1866 Feb. 21·0 B.	Schubert.	(36)
222 4 26·8	316 19 7·0	23 18 51·2	1864 Jan. 23·0 B.	Becker.	(71)
11 9 47·8	10 52 9·6	7 13 49·8	1863 Oct. 25·0 B.	Möller.	(55)
131 18 19·7	26 56 51·5	2 51 15·0	1865 Feb. 16·0 B.	Safford.	(82)
148 20 43·9	80 49 44·6	10 36 27·3	1866 Jan. 23·0 G.	Schubert.	(1)
2 30 27·3	157 21 11·5	10 22 5·1	1866 May 2·0 B.	Tietjen.	(39)
220 12 14·1	179 6 58·7	15 59 12·1	1866 July 29·5 B.	Günther.	(41)
122 1 13·5	172 42 59·1	34 42 44·7	1865 Dec. 18·0 G.	Farley.	(2)
308 55 0·5	277 43 40·8	5 14 58·0	1866 Aug. 4·5 B.	Tietjen.	(85)
7 22 10·2	197 58 59·3	3 58 54·6	1866 Jan. 0·0 B.	Franzenau.	(74)
122 55 29·6	144 41 9·9	9 21 26·3	1862 Mar. 24·0 B.	Bruhns.	(28)
345 4 58·2	44 53 11·4	7 57 34·9	1863 Dec. 20·0 B.	Wolf.	(68)
48 33 7·9	2 32 1·6	7 55 40·8	1864 Oct. 6·0 B.	Hall.	(81)
342 33 46·6	9 6 22·3	1 56 22·2	1867 Mar 29·0 W.	Schubert.	(33)
314 3 45·0	4 12 34·2	5 0 8·5	1859 June 17·0 B.	Powalky.	(47)
58 15 36·1	66 35 39·8	13 43 47·4	1866 Aug. 30·5 B.	Oppolzer.	(22)
15 26 27·0	150 33 17·6	3 3 57·2	1867 Jan. 0·0 B.	Schubert.	(16)
109 6 25·4	187 1 7·5	8 28 19·2	1861 June 3·0 B.	Celoria.	(69)
341 25 28·5	334 11 50·0	18 15 25·6	1865 Aug. 19·0 B.	R. Luther.	(61)
201 49 16·8	355 44 49·7	8 12 11·8	1867 Sept. 12·0 W.	Schubert.	(35)
32 14 49·7	290 32 17·4	3 8 46·4	1863 Nov. 14·0 B.	Powalky.	(49)
28 39 3·9	87 55 49·6	4 47 44·6	1866 Jan. 8·0 B.	Tietjen.	(86)
101 56 14·8	129 57 16·0	7 24 41·0	1858 Jan. 0·0 B.	Murmann.	(52)
74 20 42·4	185 5 29·6	6 29 28·2	1862 July 25·0 B.	Powalky.	(48)
243 23 3·0	71 17 24·5	2 15 49·2	1866 Oct. 18·0 B.	Tietjen.	(90)
34 8 29·1	126 11 42·1	2 12 17·5	1865 May 7·0 B.	Schmidt.	(62)
140 8 26·5	36 12 12·6	0 48 52·1	1864 Aug. 20·0 B.	Krüger.	(24)

TABL

Name of Planet.	Planet's Symbol.	Mean diurnal Heliocentric Motion.	Sidereal Period.	Mean distance from Sun, or Semi-axis.—(Earth's distance=1).	Excentricity.	Mean Long at Epoc
		″	days.			° ′
HYGEIA - -	(10)	634·312	2043·16	3·151151	0·100171	74 23 5
EUPHROSYNE -	(31)	633·851	20	3·152681	0·220462	104 50
MNEMOSYNE -	(57)	632·690	20	3·156535	0·104032	28 37 3
FREIA - - -	(76)	569·051	227	3·387692	0·187724	88 45 3
CYBELE - -	(65)	560·878	231	3·420519	0·120312	180 18 1
SYLVIA - - -	(87)					
	(91)					
JUPITER - -	♃	299·129	433	5·202798	0·048239	160 1 2
SATURN - -	♄	120·455	1075	9·538852	0·055996	14 50 4
URANUS - -	♅	42·233	30686·8208	19·182639	0·046578	28 26 4
NEPTUNE - -	Ψ	21·406	60126·7200	30·036970	0·008720	335 8 5

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ELEMENTS OF THE ORBITS OF MERCURY, VENUS, THE EARTH, AND MARS,
100,000 Y

(*From the investiga*

Epochs.	Excentricities.				Longitudes of Perihelion.			
	Mercury.	Venus.	Earth.	Mars.	Mercury.	Venus.	Earth.	Ma
					° ′	° ′	° ′	°
−100,000	0·1886	0·0370	0·0473	0·1079	289 37	327 48	316 18	204
− 80,000	0·1928	0·0345	0·0398	0·1251	318 2	342 21	4 13	298
− 60,000	0·1961	0·0382	0·0218	0·1125	346 26	12 36	46 8	26
− 40,000	0·2000	0·0345	0·0109	0·0832	15 4	55 33	28 36	123
− 20,000	0·2037	0·0219	0·0188	0·0840	44 23	100 56	44 0	227
0	0·2056	0·0069	0·0168	0·0932	74 20	128 43	99 30	332
+ 20,000	0·2051	0·0063	0·0047	0·1036	104 32	57 28	192 22	55
+ 40,000	0·2033	0·0088	0·0124	0·0945	134 48	74 49	6 25	139
+ 60,000	0·2008	0·0098	0·0199	0·0797	165 18	70 12	64 31	241
+ 80,000	0·1970	0·0179	0·0188	0·0948	196 11	82 33	101 38	354
+100,000	0·1918	0·0258	0·0189	0·1258	137 10	117 5	114 5	90

Continued.

Longitude of Perihelion.	Longitude of Ascending Node.	Inclination of Orbit.	Mean Solar Time of Epoch at Greenwich, Paris, Berlin, or Washington.	Authority for Elements.	Planet's Symbol.
° ' "	° "	° ' "			
235 10 29·2	286 43 1·8	3 49 0·2	1864 Feb. 22·0 B.	Zech.	(10)
93 42 6·6	31 31 45·9	26 27 5·0	1867 Jan. 0·0 B.	Schubert.	(31)
53 7 9·9	200 5 31·5	15 8 8·6	1860 Jan. 1·0 B.	Adolph.	(57)
93 13 58·1	212 58 21·4	2 1 50·8	1863 July 27·0 B.	Murmann.	(76)
258 20 36·9	158 53 34·8	3 28 9·8	1861 Jan. 0·0 B.	Fritsche.	(65)
					(87)
					(91)
11 54 53·1	98 54 20·5	1 18 40·3	1850 Jan. 1·0 P.	Annales de	♃
90 6 12·0	112 21 44·0	2 29 28·1	,, ,,	l'Observatoire	♄
168 16 45·0	73 14 14·4	0 46 29·9	,, ,,	Impérial de	♅
47 14 37·3	130 6 51·6	1 46 59·0	,, ,,	Paris.	♆

TABLE I.*

INTERVALS OF 20,000 YEARS, FROM 100,000 YEARS BEFORE A.D. 1800 TO AFTER THAT EPOCH.

of M. Le Verrier.)

Inclinations.				Longitudes of Ascending Nodes.				Epochs.
Mercury.	Venus.	Earth.	Mars.	Mercury.	Venus.	Earth.	Mars.	
° ' "	° ' "	° ' "	° ' '	° '	° '	° '	° '	
6 5 10	3 5 36	3 45 31	3 13 45	151 55	159 20	96 34	106 26	−100,000
6 30 20	4 52 37	1 18 58	1 55 12	134 43	116 57	73 47	54 13	− 80,000
7 17 30	4 4 10	2 36 42	1 1 41	116 40	71 29	136 29	163 37	− 60,000
7 25 30	0 53 8	4 3 1	2 46 15	93 54	355 5	91 59	122 20	− 40,000
7 38 10	2 12 52	2 44 12	2 46 37	69 7	118 46	41 34	87 30	− 20,000
7 0 6	3 23 28	0 0 0	1 51 6	45 57	74 52	0 0	48 0	0
6 29 50	2 8 55	2 7 46	0 53 49	22 30	15 25	124 29	322 55	+ 20,000
6 8 40	0 55 44	2 27 53	3 49 17	353 14	213 43	75 31	136 19	+ 40,000
5 49 10	2 28 36	0 51 52	4 10 49	317 6	124 25	10 47	66 50	+ 60,000
5 33 20	2 5 43	1 45 40	1 46 11	277 15	64 35	170 15	322 20	+ 80,000
5 35 20	0 21 54	3 2 57	0 49 45	240 35	275 49	109 57	145 25	+100,000

786.—Table II.

DISTANCES OF THE PLANETS FROM THE SUN AND EARTH IN MILLIONS OF MILES.

(The numbers in this Table can be read as millions and decimals of a million, or, by adding three ciphers on the right in each column, as millions and thousands: for example, the mean distance of ***Mercury*** *from the Sun is* 35·392 *in the Table, or* 35,392,000 *miles.)*

Name of Planet.	Distance from Sun.			Mean distance from Earth.	
	Greatest.	Least.	Mean.	At Superior Conjunction.	At Inferior Conjunction, or Opposition.
Mercury - -	42·669	28·115	35·392	126·822	56·038
Venus - - -	66·586	65·682	66·134	157·564	25·296
Earth - - -	92·963	89·897	91·430		
Mars - - -	152·304	126·318	139·311	230·741	47·881
Flora - - -	232·813	169·733	201·273	292·703	109·843
Ariadne - -	235·192	167·698	201·445	292·875	110·015
Feronia - - -	232·004	182·370	207·187	298·617	115·757
Harmonia - -	216·953	197·637	207·295	298·725	115·865
Melpomene -	255·577	164·203	209·890	301·320	118·460
Sappho - - -	251·994	167·908	209·951	301·381	118·521
Victoria - -	260·138	166·694	213·416	304·846	121·986
Euterpe - -	251·726	177·396	214·561	305·991	123·131
Vesta - - -	235·289	196·509	215·899	307·329	124·469
Urania - - -	243·639	188·913	216·276	307·706	124·846
Nemausa - -	230·611	201·981	216·296	307·726	124·866
Clio - - - -	267·882	165·032	216·457	307·887	125·027
Iris - - - -	268·539	167·807	218·173	309·603	126·743
Metis - - -	245·121	191·299	218·210	309·640	126·780
Echo - - - -	260·063	177·529	218·796	310·226	127·366
Ausonia - - -	246·527	191·417	218·972	310·402	127·542
Phocea - - -	275·331	163·683	219·507	310·937	128·070
Massilia - -	251·941	188·683	220·312	311·742	128·882
Asia - - - -	262·401	180·437	221·419	312·849	129·989

TABLE II. *Continued.*

Name of Planet.	Distance from Sun.			Mean distance from Earth.	
	Greatest.	Least.	Mean.	At Superior Conjunction.	At Inferior Conjunction, or Opposition.
NYSA	254·827	188·053	221·440	312·870	130·010
HEBE	266·749	176·847	221·798	313·228	130·368
BEATRIX	240·749	203·373	222·061	313·491	130·631
LUTETIA	258·769	186·577	222·673	314·103	131·243
ISIS	273·428	172·762	223·095	314·525	131·665
FORTUNA	258·591	187·799	223·195	314·625	131·765
EURYNOME	266·951	179·807	223·379	314·809	131·949
PARTHENOPE	246·504	201·856	224·180	315·610	132·750
THETIS	255·036	197·276	226·156	317·586	134·726
HESTIA	268·915	193·073	230·994	322·424	139·564
(49)	275·166	191·096	233·131	324·561	141·701
AMPHITRITE	250·786	216·232	233·509	324·939	142·079
EGERIA	256·100	215·064	235·582	327·012	144·152
ASTRÆA	279·817	191·445	235·631	327·061	144·201
IRENE	275·695	197·187	236·441	327·871	145·011
POMONA	256·194	216·918	236·556	327·986	145·126
MELETE	293·705	180·989	237·347	328·777	145·917
PANOPEA	282·686	195·176	238·931	330·361	147·501
CALYPSO	288·360	190·682	239·521	330·951	148·091
DIANA	289·080	190·516	239·798	331·228	148·368
THALIA	295·926	184·462	240·194	331·624	148·764
FIDES	284·180	198·818	241·499	332·929	150·069
EUNOMIA	286·972	196·452	241·712	333·142	150·282
VIRGINIA	311·693	172·713	242·203	333·633	150·773
MAIA	280·727	204·081	242·404	333·834	150·974
IO	288·874	196·362	242·618	334·048	151·188
PROSERPINE	264·054	221·636	242·845	334·275	151·415
CLYTIE	254·229	233·383	243·806	335·236	152·376
JUNO	306·735	181·211	243·973	335·403	152·543

TABLE II. *Continued.*

Name of Planet.	Distance from Sun.			Mean distance from Earth.	
	Greatest.	Least.	Mean.	At Superior Conjunction.	At Inferior Conjunction, or Opposition.
EURYDICE - -	319·017	169·185	244·101	335·531	152·671
FRIGGA - - -	277·472	211·116	244·294	335·724	152·864
ANGELINA - -	276·539	213·695	245·117	336·547	153·687
CIRCE - - -	271·980	219·250	245·615	337·045	154·185
CONCORDIA - -	257·388	236·388	246·888	338·318	155·458
ALEXANDRA -	296·820	199·154	247·987	339·417	156·557
OLYMPIA - -	277·147	218·971	248·059	339·489	156·629
EUGENIA - -	268·684	228·916	248·800	340·230	157·370
LEDA - - - -	289·473	211·591	250·532	341·962	159·102
ATALANTA - -	326·711	175·447	251·079	342·509	159·649
NIOBE - - -	295·700	208·168	251·934	343·364	160·504
PANDORA - -	288·773	215·751	252·262	343·692	160·832
ALCMENE - -	309·409	195·335	252·372	343·802	160·942
CERES - - -	273·262	232·656	252·959	344·389	161·529
LÆTITIA - - -	282·002	223·986	252·994	344·424	161·564
DAPHNE - - -	320·512	185·854	253·183	344·613	161·753
PALLAS - - -	313·990	192·460	253·225	344·655	161·795
THISBE - - -	295·076	211·480	253·278	344·708	161·848
GALATEA - -	314·459	193·471	253·965	345·395	162·535
BELLONA - -	292·166	215·906	254·036	345·466	162·606
LETO - - - -	302·121	206·303	254·212	345·642	162·782
TERPSICHORE -	316·452	205·850	261·151	352·581	169·721
POLYHYMNIA -	350·666	173·060	261·863	353·293	170·433
AGLAIA - - -	298·216	228·648	263·432	354·862	172·002
CALLIOPE - -	292·350	239·902	266·126	357·556	174·696
PSYCHE - - -	303·514	231·110	267·312	358·742	175·882
HESPERIA - -	318·932	224·472	271·702	363·132	180·272
DANAË - - -	317·002	228·794	272·898	364·328	181·468
LEUCOTHEA - -	334·608	215·186	274·897	366·327	183·467

TABLE II. *Continued.*

Name of Planet.	Distance from Sun.			Mean distance from Earth.	
	Greatest.	Least.	Mean.	At Superior Conjunction.	At Inferior Conjunction, or Opposition.
PALES - - -	348·686	214·980	281·833	373·263	190·403
SEMELE - - -	340·509	224·673	282·591	374·021	191·161
EUROPA - - -	312·174	254·686	283·430	374·860	192·000
DORIS - - -	306·080	262·506	284·293	375·723	192·863
ANTIOPE - -	327·265	243·045	285·155	376·585	193·725
ERATO - - -	334·690	237·598	286·144	377·574	194·714
THEMIS - - -	320·971	253·769	287·370	378·800	195·940
HYGEIA - - -	316·970	259·250	288·110	379·540	196·680
EUPHROSYNE -	351·798	224·702	288·250	379·680	196·820
MNEMOSYNE -	318·626	258·578	288·602	380·032	197·172
FREIA - - -	367·882	251·592	309·737	401·167	218·307
CYBELE - - -	350·364	275·112	312·738	404·168	221·308
SYLVIA - - -					
(91) - - - -					
JUPITER - - -	498·639	452·745	475·692	567·122	384·262
SATURN - - -	920·973	823·301	872·137	963·567	780·707
URANUS - - -	1835·561	1672·177	1753·869	1845·299	1662·439
NEPTUNE - -	2771·190	2720·806	2745·998	2837·428	2654·560

A general impression of the relative magnitudes of the different planets is conveyed to the mind by a simple illustration first suggested by Sir J. Herschel. Suppose we take a globe, two feet in diameter, and place it in a well-levelled field or bowling-green. Let this globe represent the sun. Then at the relative distances of the planets, Mercury will be represented by a grain of mustard seed; Venus, a pea; the Earth, also a pea; Mars, a rather large pin's head; the minor planets as grains of sand; Jupiter, a moderately-sized orange; Saturn, a small orange; Uranus, a full-sized cherry, or small plum; and Neptune, a middle-sized plum. 'As to getting correct notions on this subject by drawing circles on paper, or, still worse, from those childish toys called orreries, it is out of the question.'

786 *a*.—**Rough elements of the orbit of the November ring of meteorolites.**—Observers are now generally of opinion that these apparently wandering bodies are really members of our solar system, having an extraneous or cosmical origin, and revolving in definite orbits around the sun. From the periodic observations of showers of these meteor-planets, we may infer that as the earth is pursuing its course in its orbit, it passes, at stated intervals, through or near rings of these small bodies, which on coming in contact with the earth's atmosphere become ignited. Mr. H. A. Newton, an American mathematician, has discussed in considerable detail the observations of remarkable meteoric showers, from which he has deduced rough elements of the meteors composing the November ring. The following notes contain a few of his results. 1. A glance at the observed dates of the showers shows that there is a cycle in about the third part of a century, and that during the two or three years at the end of each cycle, showers may be expected. The exact length of the cycle is 33·25 years. 2. The time of a sidereal revolution of the meteoric group around the sun is 354·621 days. 3. Each body has its own elliptic orbit about the sun, this orbit being slightly modified by the action of the rest of the group. It is probable that all these ellipses are equal, or the meteors would soon scatter themselves along the whole circuit of the ring, and there would be a display every year. 4. The semi-major axis of the mean of these orbits is 0·98049, the mean distance of the earth being unity. 5. The excentricity is evidently small, probably differing no more than two or three degrees from a right angle. The ring would therefore be nearly circular The inclination of the orbit to the ecliptic is about 17°. 6. The velocity with which the meteors enter the atmosphere in the opposite direction to the earth's motion is about 20 miles a second, giving an apparent velocity of nearly 40 miles a second. 7. The length of the November group is supposed to be about 40 millions of miles. If a shower last five hours, the thickness of the ring would be the distance passed over by the earth in that interval of time multiplied by the sine of the inclination, or more than 100,000 miles.

The general observation of the magnificent display of meteors on the night of November 13, 1866, will give data which will probably slightly alter the results obtained by Mr. Newton. At Greenwich nearly 10,000 were observed. The radiant point from which the paths of the meteors appeared to diverge during this display, was near x Leonis, a small star between γ and ϵ Leonis. The inclination of the orbit of the ring of meteors, as found from a discussion of these observations, is about 19°.

787.—TABLE III.

Name of Planet.	Apparent Equatorial Diameter at Mean Distance from Earth.	Mean Diameter.		Ellipticity.	Linear Value of 1″ at Mean Distance from Earth.	Surface.		Volume.
		Earth's = 1.	Miles.		Miles.	Earth's = 1.	Millions of Square Miles.	Earth's = 1.
MERCURY	6″·90	0·387	3058		443·3	0·149	29·504	0·0577
VENUS	16·94	0·949	7510		443·3	0·901	177·137	0·855
EARTH	- -	1·000	7912	$\frac{1}{299·26}$	- -	1·000	196·600	1·000
MARS	6·46	0·551	4363	$\frac{1}{60}$	675·4	0·304	59·784	0·168
JUPITER	37·91	10·724	84846	$\frac{1}{16·87}$	2306·2	114·998	22608·607	1233·205
SATURN	17·52	8·865	70136	$\frac{1}{9·44}$	4228·2	78·588	15450·400	696·685
URANUS	3·91	4·202	33247		8503·0	17·658	3471·563	74·199
NEPTUNE	2·80	4·711	37276		13313·0	22·197	4363·930	104·575
SUN	1924·20	107·799	852908		443·3	11620·600	2284627·000	1252691·000
MOON	1869·58	0·2735	2164		1·158	0·0748	14·700	0·0205

788.—Table IV.

Name of Planet.	Mass.		Density.		Apparent Diameter of Sun at Mean Distance of Planet.		Solar Light and Heat.	Rotation on Axis.			Inclination of Axis to Orbit.		
	Earth's = 1.	Sun's = 1.	Earth's = 1.	Water's = 1.	At Earth = 1.	Angular Value in Seconds.	At Earth = 1.	Mean Solar Time. h.	m.	s.	°	′	″
Mercury	0·065	$\frac{1}{4865751}$	1·12	6·35	2·584	4972	6·670	24	5	28		?	
Venus	0·885	$\frac{1}{355932}$	1·03	5·84	1·383	2660	1·910	23	21	15		?	
Earth	1·000	$\frac{1}{315000}$	1·00	5·67	1·000	1924	1·000	23	56	4	23	27	24
Mars	0·118	$\frac{1}{2680337}$	0·70	3·97	0·656	1262	0·430	24	37	23	28	27	0
Jupiter	300·860	$\frac{1}{1047}$	0·24	1·36	0·192	370	0·036	9	55	26	3	5	30
Saturn	89·692	$\frac{1}{3512}$	0·13	0·74	0·105	202	0·011	10	29	17	26	48	40
Uranus	12·650	$\frac{1}{24900}$	0·17	0·97	0·052	100	0·003	9	30	?		?	
Neptune	16·773	$\frac{1}{18780}$	0·16	0·91	0·033	64	0·001	-		-		?	
Sun	315000·000	1	0·25	1·42	- -	- -	- -	607	48	0	7	20	0
Moon	0·0125	$\frac{1}{25200000}$	0·60	3·40	1·000	1924	1·000	655	43	5	-		-

789.—TABLE V.

Name of Planet.	Superficial Gravity.		Orbital Velocity.			Velocity of Rotation at Equator.		Gravitation towards Sun.	
	Earth's =1.	Fall: Feet in 1 Second.	Earth's=1.	Miles per Hour.	Feet per Second.	Miles per Hour.	Feet per Second.	Terrestrial Gravity=1.	Fall: Thousandths of an Inch in 1 Second.
MERCURY - -	0·432	6·953	1·6072	105325	154476	399	585	$\frac{1}{253}$	763·40
VENUS - - -	0·982	15·805	1·1758	77054	113012	1011	1483	$\frac{1}{884}$	218·48
EARTH - - -	1·000	16·095	1·0000	65533	96115	1039	1524	$\frac{1}{1690}$	114·29
MARS - - -	0·387	6·229	0·8101	53088	77863	558	818	$\frac{1}{3924}$	49·22
JUPITER - - -	2·611	42·024	0·4386	28743	42156	27726	40665	$\frac{1}{45750}$	4·22
SATURN - - -	1·141	18·364	0·3238	21220	31122	22216	32583	$\frac{1}{153810}$	1·26
URANUS - - -	0·716	11·524	0·2283	14961	21943	11010	16148	$\frac{1}{621899}$	0·31
NEPTUNE - -	0·756	12·168	0·1825	11960	17541	?	?	$\frac{1}{1524652}$	0·13
SUN - - - -	27·107	436·287	- -	- -	- -	4415	6475	- -	- -
MOON - - -	0·167	2·688	0·0334	2189	3210	10·4	15·3	$\frac{1}{1690}$	114·29

The increase in the sun's parallax necessitates a corresponding alteration in the hitherto adopted value of the earth's mass. M. Le Verrier is known to be engaged in its investigation. In reply to a question on the subject, he remarks:—" Maintenant qu'on sait que l'ancienne masse de la Terre ne peut être conservée, il y a à reprendre les déterminations en ne conservant que le nombre d'inconnues strictement nécessaires. C'est seulement quand j'aurai fini ce travail, dont je m'occupe, que je pourrai vous répondre."

The mass adopted in this work has been obtained from the formula in Le Verrier's Solar Tables published in the *Annales de l'Observatoire Impérial de Paris.*

791.—TABLE

SYNOPSIS OF THE MOTION OF THE ELLIPTIC
WITHIN THE

(Winnecke's Comet is probably the same

Name of Comet.	Mean Distance from Sun. Earth's = 1.	Excentricity.	Perihelion Distance. Earth's = 1.	Aphelion Distance. Earth's = 1.	Mean Daily Motion.
	a	e	$a\times(1-e)$	$a\times(1+e)$	h
Encke - - - -	2·2181	0·8464	0·3407	4·0955	1074'·1
Blainpain (1819) -	2·8490	0·6867	0·8926	4·8054	737·8
Burckhardt (1766)	2·9337	0·8640	0·3990	5·4684	706·1
Clausen (1743) -	3·0913	0·7213	0·8615	5·3211	652·8
De Vico - - - -	3·1028	0·6173	1·1874	5·0182	648·8
Winnecke - - -	3·1343	0·7547	0·7688	5·4998	639·4
Brorsen - - - -	3·1465	0·7945	0·6466	5·6464	635·7
Lexell (1770) - -	3·1560	0·7861	0·6751	5·6369	632·8
Pons (1819) - -	3·1602	0·7552	0·7736	5·5468	631·6
D'Arrest - - -	3·4618	0·6609	1·1739	5·7497	556·2
Biela - - - - -	3·5308	0·7563	0·8605	6·2011	534·8
Faye - - - - -	3·8118	0·5576	1·6863	5·9373	478·6
Pigott (1783) - -	4·6496	0·6784	1·4953	7·8039	353·9
Peters (1846) - -	6·3206	0·7567	1·5378	11·1034	221·9

790. THE MOON.

Mean distance from the earth	59·96435 semi-diameters of earth.
Mean sidereal revolution -	27^{d} 7^{h} 43^{m} $11^{s}·5$
Mean tropical revolution -	27 7 43 4·7
Mean synodical revolution -	29 12 44 2·9
Mean longitude at epoch, (1801, Jan. 1.) - -	118° 17′ 8″·3
Mean longitude of perigee, (1801, Jan. 1.) - -	266 10 7·5
Mean longitude of ascending node, (1801, Jan. 1.) -	13 53 17·7
Inclination of orbit - -	5 8 47·9
Excentricity of orbit - -	0·0548442

VI.

COMETS, WHOSE ORBITS ARE CONTAINED
ORBIT OF SATURN.

as that discovered by Pons in 1819.)

Period in Years.	Longitude of Perihelion.	Longitude of Ascending Node.	Inclination of Orbit.	Mean Time of Perihelion Passage.	Direction of Motion.
P	ϖ	ν	i	Mean Solar Time at Greenwich or Berlin.	
	° ′ ″	° ′ ″	° ′ ″	d h	
3·303	157 57 30	334 28 34	13 4 15	1858 Oct. 18 12 B	D
4·809	67 18 48	77 13 57	9 1 16	1819 Nov. 20 6 G	D
5·025	251 13 0	74 11 0	8 1 45	1766 April 27 0 G	D
5·435	93 19 35	86 54 29	1 53 43	1743 Jan. 8 5 G	D
5·469	342 31 15	63 49 31	2 54 45	1844 Sept. 2 11 G	D
5·549	275 38 52	113 32 49	10 48 4	1858 May 30 0 B	D
5·581	116 28 24	102 37 41	30 57 51	1846 Feb. 25 8 G	D
5·607	356 17 12	131 59 17	1 34 28	1770 Aug. 13 13 G	D
5·618	274 40 51	113 10 46	10 42 48	1819 July 18 22 G	D
6·380	323 3 13	148 27 16	13 56 6	1858 Jan. 2 0 B	D
6·635	109 8 21	245 52 29	12 33 17	1852 Sept. 28 16 G	D
7·414	49 56 55	209 41 53	11 22 7	1865 Oct. 4 0 B	D
10·025	49 31 55	55 12 0	47 43 0	1783 Nov. 19 13 G	D
15·990	239 49 51	260 12 25	13 2 14	1846 June 1 3 G	D

792. **Diagram of their orbits.**—In *fig.* 108, the orbits of these comets are brought to a common plane, and represented roughly only in their proportions and relative positions, so as to exhibit to the eye their several ellipticities, and the relative directions of their axes.* These bodies all revolve in the common direction of the planets.

793. **Planetary character of their orbits.**—It is not alone, however, in the direction of their motions, that the orbits of these bodies have an analogy to those of the planets. Their inclinations, with one exception, are within the limits of those of the planets. Their excentricities, though incomparably greater than those of the planets, are, as will presently appear, incomparably less than those of all other comets yet discovered. Their mean distances and periods (with the exception of the last two in the table) are within the limits of those of the planetoids.

The comparison of the numbers given in Table VI. with those which are given in the table of the elements of other elliptic comets, and the comparison of the diagrams of their orbits with those of others, will show in a striking manner to how great an extent the orbits of this group of comets possess the planetary character. Besides moving round the sun in the common direction, their inclinations, with a single exception, are within the limits of those of the planets. It is true that their excentricities have an order of magnitude much greater; but on the other hand, they are incomparably less than the excentricities of all other periodic comets yet discovered. Their mean distances and periods place them in direct analogy with the planetoids.

Moderate as are the excentricities as compared with those of other comets, they are sufficiently great to impart a decided oval form to the orbits, and to produce considerable differences between the perihelion and aphelion distances, as will be apparent by inspecting the numbers in Table VI. It appears by these that while the perihelion of Encke's comet lies within the orbit of Mercury, its aphelion lies outside the orbit of the most remote of the planetoids, and not far within that of Jupiter. The perihelion of Biela's comet, in like manner, lies between the orbits of the earth and Venus, while its aphelion lies outside that of Jupiter. In the case of Faye's comet, the least excentric of the group, the perihelion lies near the orbit of Mars, and the aphelion outside that of Jupiter.

It must be remembered that the elliptic form of these orbits has only been verified by observations on the successive returns to perihelion of the comets of Encke, De Vico, Brorsen, D'Arrest,

* In the diagram, to prevent confusion, the orbits of the different comets are indicated by dotted or broken lines of different kinds.

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* In the diagram, to prevent confusion, the orbits of the different comets are indicated by dotted or broken lines of different kinds.

795. **Planetary characters are nearly effaced in these orbits.**—By comparing the elements given in Table VII., and the forms and magnitudes of the orbits shown in the diagram, with those of the first group of elliptic comets given in Table VI., and drawn in *fig.* 108, it will be perceived that the planetary characteristics, noticed in the latter groups, are nearly effaced. Five of the six comets composing the second group, revolve in the common direction of the planets, and this is the only planetary character observable among them. The inclinations are no longer limited to those of the planetary orbits, and range from 18° to 74°. The excentricities are all so extreme, that the arc of the orbit near perihelion approximates closely to the parabolic form, and finally, the most remarkable body of the group, the comet of Halley, revolves in a direction contrary to the common motion of the planets.

But this group of comets differs more particularly in the elongated oval form of their orbits, from those of the planets, and even from those of the nearer group of comets. While their perihelia are at distances from the sun between those of Mars and Mercury, their aphelia are from two to five hundred millions of miles outside the orbit of Neptune. For example, the comet of Halley in perihelion is at a distance from the sun less than that of Venus; but at its aphelion, its distance exceeds that of Neptune by a space greater than the distance of Jupiter from the sun. The mean angular motion of this comet is nearly the same as that of Uranus, but its angular motion in perihelion is three times that of Mercury, while in aphelion it amounts to little more than a half that of Neptune.

The corresponding variations of solar light and heat, and of the apparent magnitude and motion of the sun as seen from the comet, may be easily inferred.

In comets of great excentricity and long period, in which the elliptic form of the orbit has been established, the periodicity has not yet in any instance been certainly established by observations made upon their successive returns to perihelion; notwithstanding this, however, the observations made upon them during a single perihelion passage, indicate an arc of their orbit which exhibits the elliptic form so unequivocally, as to supply mathematicians and computers with the data necessary to obtain, with more or less approximation, the value of the excentricity, which, combined with the perihelion distance, gives the form and magnitude of the comet's orbit.

By calculations conducted in this manner, and applied to the observations made on various comets which have appeared since the latter part of the seventeenth century, the elliptic orbits of between twenty and thirty of these bodies have been computed.

796.—TABLE

SYNOPSIS OF THE MOTION OF THE ELLIPTIC COMETS, THAT OF

Name of Comet.	Mean Distance from Sun. Earth's=1.	Excentricity.	Perihelion Distance. Earth's=1.	Aphelion Distance. Earth's=1.	Mean Daily Motion.
	a	e	$a\times(1-e)$	$a\times(1+e)$	h
					″
Westphal (1852) -	16·6200	0·9248	1·2510	31·9700	52·4
Pons (1812) - -	17·0955	0·9545	0·7771	33·4140	50·7
De Vico (1846) -	17·5386	0·9544	0·6631	34·3510	48·4
Olbers (1815) - -	17·6338	0·9312	1·2129	34·0550	47·9
Brorsen (1847) -	17·7795	0·9726	0·4879	35·0710	47·3
Halley - - - -	17·9875	0·9674	0·5866	35·3660	46·3

797. **Distribution of the cometary orbits in space.**—In reviewing the vast mass of data collected by the labours of observers, ancient and modern, which is considered sufficiently trustworthy to admit of classification, it is natural to look for some evidence of a prevalent law in the motions of these bodies. The absence of all analogy to the planetary orbits, except in the case of the group of elliptic comets of short period, has been already indicated; but although no analogy to the planetary motions may exist, it does not follow that the cometary motions may not be governed by some laws of their own, the nature and character of which can only be discovered by carefully conducted induction.

798. **Relative numbers of direct and retrograde comets.**—It has been shown that of the twenty comets included in Tables VI. and VII., which possess in the most marked degree the planetary character, one only is retrograde.

To ascertain whether traces of the same law are discoverable in the other classes of comets having elliptic orbits of long period or parabolic orbits, it is necessary to examine the direction of those whose orbits have been computed. Taking, therefore, 203 comets of which the direction is ascertained, it is found that the number of those having direct motion is 104 and those having retrograde motion 99. It must therefore, be concluded that, notwithstanding the considerable number of comets whose motions have been ob-

VII.

WHOSE MEAN DISTANCES ARE NEARLY EQUAL TO URANUS.

Period in Years.	Longitude of Perihelion.	Longitude of Ascending Node.	Inclination of Orbit.	Mean Time of Perihelion Passage.	Direction of Motion.
P	ϖ	☊	i	Greenwich Mean Time.	
				d. h.	
67·770	43 12 16	346 13 25	40 58 32	1852 Oct. 12 15	D
70·068	92 18 44	253 1 2	73 57 3	1812 Sept. 15 8	D
73·250	90 34 46	77 35 36	84 57 13	1846 March 5 14	D
74·050	149 1 56	83 28 34	44 29 55	1815 April 25 23	D
74·970	79 12 46	309 48 49	19 8 25	1847 Sept. 9 13	D
76·680	304 31 32	55 9 59	17 45 5	1835 Nov. 15 23	R

served, no general trace of any law governing the direction of motion is discoverable.

799. **Inclination of the orbits.**— There are evident indications of a tendency of the planes of the cometary orbits to collect round a plane whose inclination to the plane of the ecliptic is 45°, or if a cone be imagined to be formed having a semi-angle of 45°, and its axis at right angles to the plane of the ecliptic, the planes of the cometary orbits betray a tendency to take the position of tangent planes to the surface of such a cone.

800. **Distribution of the points of perihelion.**— Considering how much the visibility of a comet from the earth depends on its perihelion distance, and that beyond a certain limit of such distance a comet cannot be expected to be seen at all, it cannot be thought that the law, if any such there be, which governs the distribution of the points of perihelion round the sun, can be discovered with any degree of certainty. Nevertheless it will not be without interest to show the distribution of the points of perihelion of the known comets in relation to their distances from the sun.

If the centre of the sun be imagined to be surrounded by spheres having semi-diameters increasing successively by a constant increment of 20 millions of miles, the number out of every hundred known comets whose perihelia lie between sphere and sphere, will be as follows: —

	Number of Perihelia.
Within 20 millions	8·65
Between 20 and 40	11·70
40 „ 60	20·30
60 „ 80	17·20
80 „ 100	20·80
100 „ 120	8·65
120 „ 140	4·55
140 „ 160	4·05
160 „ 180	2·00
180 „ 220	1·55
220 „ 420	0·55
	100·00

It is evident that the small proportion of the perihelia which lie outside the sphere, whose radius is 120 millions of miles, must be ascribed to the fact that comets moving in such orbits will mostly escape observation; but it may, perhaps, be assumed that the comets whose perihelia lie within a sphere through the earth's orbit have nearly equal chances of being observed. If this be assumed, then it will follow that the numbers of such comets which have been observed are nearly proportional to their total numbers, and therefore that the numbers within this limit in the preceding table do actually represent approximately the distribution of the points of perihelia round the sun.

If we compare then the number of perihelia situate between the equidistant spheres indicated in the preceding table with the cubical spaces through which they are respectively distributed, we shall obtain an approximate estimate of the *density* of their distribution in relation to the distances from the sun. We have computed the following table with this view. In the second column is given the number of comets per cent., whose perihelia are included between the equidistant spheres; in the third column the numbers express the cubical spaces between sphere and sphere, the volume of the sphere whose radius is 20 millions of miles, being the cubical unit; and in the fourth column the numbers are the quotients of those in the second divided by those in the third, and therefore express the successive densities of the perihelia between sphere and sphere.

	Number of Perihelia.	Cubical Space.	Density of Perihelia.
0 to 20	8·65	1	8·65
20 „ 40	11·70	7	1·67
40 „ 60	20·30	19	1·06
60 „ 80	17·20	37	0·47
80 „ 100	20·80	61	0·34
100 „ 120	8·65	91	0·095

It is evident then, that the density of the perihelia increases rapidly in approaching the sun. If the numbers in the last column of the table be compared with the inverse powers of the distance, it will be found that this increase of density is more rapid than the inverse distance, but less so than the inverse distance squared.

800 *a*. **Suggested connection between comets and meteorolites.**—The successful observation of the great display of meteors on the night of November 13–14, 1866, has drawn the attention of several astronomers to the possible origin of this class of cosmical bodies. M. Schiaparelli, of Milan, in a series of letters to M. Secchi, has exhibited several apparent analogies between the orbits of comets and meteorolites, and he has considered that this possible connection may be a fair assumption, if we can imagine the existence of united systems, in which an accumulation of small bodies might be congregated around one or more nuclei of greater magnitude.

From an examination of M. Schiaparelli's speculations, we gather that if a mixed system of this kind were brought near us, by the attraction of the sun, under the form of a parabolic ring, the parabolas described by the principal bodies ought to differ but slightly from the parabola described by the ring of the smaller ones. This is evident, because the ring is formed by an infinite number of parabolas massed together, in the midst of which is the parabola of the principal body. Consequently, when we find a meteoric ring, the elements of whose orbit are identical in magnitude and position with those of any comet, we may naturally infer that the comet forms part of that ring, and would be one of its constituent members.

According to this hypothesis, M. Schiaparelli has determined the elements of the parabolic orbit described in space by the ring

of meteorolites of August 10. The results were found to agree sensibly with the elements of the great comet of 1862, from the latest calculation of M. Oppolzer. They can be best compared by placing the two sets of elements side by side as follows:—

	Elements of the August ring of Meteorolites.	Elements of Comet II. 1862.
Perihelion passage . .	1866 July 23·62	1862 Aug. 22 9
Ascending Node passage .	" Aug. 10·75	...
Longitude of Perihelion . .	343° 28′	344° 41′
Longitude of Ascending Node .	138 16	137 27
Inclination of Orbit . . .	64 3	66 25
Perihelion distance . . .	0·9643	0·9626
	Motion retrograde.	Motion retrograde.

From elliptic elements by M. Stampfer, the period of the comet is found to be 113 years. M. Schiaparelli has shown from records of extraordinary showers of meteors, that the period of the August ring does not differ from the above to any great extent. He remarks: "We see that the two systems of elements differ between themselves only by such quantities which might be easily attributed to a want of precision in the determination of the position of the node of the meteorolites, or to that of their point of divergence. I find even that in making slight changes in the co-ordinates of this point, most of the differences almost entirely disappear. I have then come to the conclusion, that the great comet of 1862 is no other than one of the August meteors, and it is probably the most considerable of them all."

If the opinion expressed by M. Schiaparelli be not borne out by subsequent investigations, it must be acknowledged that the coincidence is very remarkable. No elements of any known comet, however, have been found to agree with those of the November ring of meteorolites. It is assumed that this group, having comparatively so short a period, might not have any considerable nucleus, or if there had been one, that it has become invisible to us. M. Le Verrier has also published some remarks on this subject, his hypothesis being something analogous to that of M. Schiaparelli. He, however, merely shows the possibility of his reasoning, without committing himself to any positive assertions.*

* Since the publication of these researches, Dr. C. A. F. Peters, of Altona, has pointed out the remarkable fact that the elements of the orbit of Comet I. 1866, are nearly identical with those of the orbit of the November ring of meteorolites, as computed by M. Schiaparelli.

APPENDIX.

The following brief abstracts and notes of some of the principal processes and researches which have occupied the attention of astronomers during the last few years, will, in some cases, give the peculiarities of the subject in fuller detail than can be found in the preceding pages.

801. **Description and use of the Greenwich chronograph.**—On page 18, we have briefly described the general method of observing transits by eye-and-ear with the transit instrument, and we have also mentioned that in many observatories transits are now observed by the chronographic method. As the registration of transits by the chronograph has become the ordinary method in the daily observations at the Royal Observatory, and as the adoption of the system becomes every year more general, we believe that a detailed description of the apparatus will be acceptable. It may be remarked, that different plans of construction have been used at different places, but the leading principle is the same in all. The Greenwich instrument may therefore be taken as a general type of the others.

The chronograph consists of two distinct portions, a recording cylinder, and a clock for driving the cylinder. Since the flow of time is uniform, the cylinder, which is covered with paper for the reception of the record, must also turn uniformly. The clock (used solely for driving the cylinder) is therefore provided with a pendulum having conical motion. Uniform motion is thus obtained. By the side of the cylinder two long screws are placed. These are turned slowly by the clock. On the screws a frame travels carrying the recording apparatus. This consists of two electro-magnets, each of which, by attracting an armature, causes a steel point to puncture the paper on the cylinder. Now, in the transit-clock means are provided for closing a galvanic circuit at each beat of the pendulum. Wires from the clock pass to one of the electro-magnets of the chronograph. At every beat of the pendulum of the transit-clock, therefore, a galvanic current flows to the electro-magnet, its armature is pulled, and a puncture made in the paper on the cylinder. As these punctures are made, the recording

frame is travelling in a direction parallel to the axis of the cylinder, the punctures therefore form a spiral row of dots from one end of the cylinder to the other. Once each minute, no contact is made by the transit-clock; the omission of the corresponding puncture marks, with certainty, the commencement of each minute. From the second of the two electro-magnets, wires pass to the transit-circle, the altazimuth, and the great equatorial. The observations made with these three instruments may therefore be registered simultaneously. An ivory key, or contact-piece, is placed on the eye-end of the transit-circle and equatorial, and within reach of the observer with the altazimuth. As the object to be observed, say a star, becomes bisected by each wire in succession, the observer completes the circuit, by pressing the contact-piece, which causes corresponding records to be made on the revolving cylinder between the seconds' punctures of the transit-clock. This completes the observation. It is now, however, necessary to identify the proper punctures for each observation. This is never performed till the following morning. It is the duty of an assistant to mark the time corresponding to the transit-clock punctures; the names of the objects observed on the preceding evening are also marked on that part of the paper at which each transit is recorded. The time of transit over each wire is then read, and entered into the transit-book, which is finally handed over to the computer for the systematic reduction of the observations. The cylinder is large enough to contain five or six hours of continuous work. When the paper on one is filled with punctures, another is substituted, there being five in reserve. After the observations have been read off as described, the paper is removed from the cylinder and carefully preserved in the archives of the Observatory.

The Greenwich chronograph has been in constant use since the year 1854. Among the great advantages of the chronographic method of recording transits are: 1. That the record is unquestionably free from doubt; as it is sent by the observer, so it permanently remains. 2. That, by this method, the transits made with several instruments are all referred to one clock, thus avoiding the necessity of making comparisons between the time as shown by different clocks. 3. That greater accuracy is obtained over the old method, as can be seen by reference to the numbers on page 19.*

* For an account of the comparative accuracy of the old and new methods of observing transits, the reader is referred to a paper in the *Monthly Notices of the Royal Astronomical Society*, vol. xxiv. p. 152, "On the probable error of a meridional transit observation by the 'eye and ear,' and chronographic methods." By Edwin Dunkin, F.R.A.S.

802. **Reduction of meridional observations.**—In paragraph 23 *et seq.* we have briefly described the general construction and use of meridional instruments, and have also explained the usual adjustments required before they can be used for astronomical observations. The final adjustments are, however, frequently made about the time of observation, and corrections for the errors of collimation, level, and azimuth of the transit instrument are always applied in the reductions, as will be seen below. As inquiries are often made on this subject, we consider it will be probably useful to the amateur computer if we now add complete examples of the reduction of an actual observation of a star, on the meridian of Greenwich, made with the transit-circle. It will tend to clearness if we make our reduction a fac-simile of that contained in the archives of the Royal Observatory, beginning with a transit observation.

		d.	h.	m.
Approximate Solar Time	1864 Nov.	9	22	50.
Name of Object	Arcturus.			
Approximate N.P.D. of Object	70° 6′			
Observer	D.			
Reading of Transit Micrometer	31.000.			

	h.	m.	s.
			9.4
			12.5
			15.4
			18.3
Transit over separate wires			24.2
			30.0
			32.9
			36.0
	14	9	38.8
			9)217.5
			24.16
Correction to central wire			− 0.05
Observed Transit	14	9	24.11
Collimation Error $-3''.71$			− .26
			23.85
Level Error $+10''.73$			+ .66
			24.51
Azimuthal Error $-3''.69$			− .14
True Transit over Meridian	14	9	24.37
Clock slow at 0^h Sidereal preceding			4.84
Adopted Losing Rate $-0^s.40$			− .24
OBSERVED R.A. OF OBJECT	14	9	28.97
Star's correction with sign changed			− 1.43
OBSERVED MEAN R.A. JAN. 1, 1864	14	9	27.54

In the preceding observation the three instrumental errors were obtained as follows:—

Collimation.—The coefficient of this error (26) is daily determined by the observation of the coincidence of the transit-circle middle wire with wires placed in the eye-end of two opposite telescopes, or collimators, whose object-glasses are turned towards the centre of the instrument, the collimator wires having been previously adjusted on each other. In practice it is usual to leave the micrometer of the transit-telescope at some convenient reading, near to that for the true line of collimation, the difference of the two readings being the error of collimation. The numerical correction to the observations, in seconds of time, is

$$\text{Error of collimation} \times \frac{1}{15 \sin \text{N.P.D.}}$$

Level.—The error of level (25) is ascertained by the use of an eye-piece invented by M. Bohnenberger, consisting of three lenses and a transparent glass reflector, the surface of which is placed at an angle of 45° with the axis of the eye-piece. The observation is made as follows: The telescope is placed in a vertical position with the object-glass downwards, a trough of quicksilver being directly under the object-glass. By this means the images of the central wire are viewed by reflection and direct vision at the same time. The two images are then made to coincide by turning a micrometer screw, six readings being generally taken. The difference between the mean of all the micrometer readings and that adopted for the true line of collimation of the telescope is the error of level. The error in terms of micrometer-reading is then converted into seconds of arc for use in the reductions. The numerical correction for each observation is

$$\text{Error of level} \times \frac{\cos \text{ zenith distance}}{15 \sin \text{N.P.D.}}$$

Azimuth.—The azimuthal error (27) is obtained, when possible, by the comparison of the observations of consecutive transits of Polaris above and below the pole. When, from cloudy weather, a single observation only of Polaris is made, the error is determined from a combination of the observations of that star and one situate near the equator. The method of reduction is fully explained in the introduction to the *Greenwich Observations.* "The letter z being put for the azimuthal error; the time of true transit of any star consists of an observed time with an additional term multiplied by z, and, therefore, the clock-error, as given by comparison of that transit with the star's tabular R. A., contains a term multiplied by z. The clock-error given thus by a star near the pole contains a large multiple of z. The clock-error given by a star far from the

pole contains a small multiple of *z*. Equating these, with proper allowance for the rate of clock, *z* is found. The combination of two stars, both near the pole, but one above and the other below the pole, is very favourable, as both factors of *z* are large, but have opposite signs." δ Ursæ Minoris and Cephei 51 (Hev.), whose difference of right ascension is about twelve hours, are, next to Polaris, the most valuable stars for the determination of the azimuthal error. The following examples are given as illustrations of both methods of reduction, the first being by consecutive transits of Polaris.

		d. h.		h. m. s.	s.
1864.	Nov.	9 10.	Transit of Polaris . . .	1 10 32·86	
					−11·91
		9 22.	Transit of Polaris S.P. . .	13 10 44·77	
					−12·90
		10 10.	Transit of Polaris . . .	1 10 31·87	
				Mean .	= −12·40

$$z = \frac{-12{\cdot}40}{3{\cdot}360} = -3''{\cdot}69.$$

The azimuthal error in the second example is determined from the comparison of one transit of Polaris with a transit of an equatorial star, ε Piscium.

		d. h.		h. m. s.
1864.	Nov.	8 10.	Transit of ε Piscium . . .	0 55 52·75 + z × 0·047
			R.A. of ε Piscium . . .	0 55 57·63
				4·88
			Rate of clock −0^s·40 .	00
			Clock slow . . .	4·88 − z × 0·047
		8 10.	Transit of Polaris . . .	1 10 33·96 − z × 1·628
			R.A. of Polaris . . .	1 10 43·09
				9·13 + z × 1·628

$$z = \frac{-4{\cdot}25}{1{\cdot}675} = -2''{\cdot}54.$$

The factors used in these reductions are printed in a tabular form in the volume of *Greenwich Observations*. The numerical correction to the observed transit is

$$\text{Azimuthal error} \times \frac{\text{sin zenith distance south}}{15 \text{ sin N.P.D.}}$$

By the application of these three corrections to the observed clock-time of transit, the true transit over the meridian, referred to the transit-clock, is found. The apparent right ascension of the object is then easily computed by applying the clock-error, which is always determined from the observations of special stars, whose tabular places are known with considerable accuracy.

The following calculation is for the corresponding observation of Arcturus in zenith and north polar distance.

	d. h. m.
Approximate Solar Time	1864. Nov. 9 22 50.
Name of Object	Arcturus.
Approximate R.A. of Object	14h. 9m.
Mode of Observation	Direct.
Wire at which observation was made	4.
Observer	D.
	° ′
Pointer	31 15
Micrometer reading of Microscope A	1·210
B	1·645
C	1·171
D	1·249
E	1·401
F	1·336
Uncorrected Mean of Microscopes	31 16 20·12
First Part of Correction for Runs	1·60
Second Part +0″·302 for 100″	·24
Micrometer Reading, and Equivalents 21·435 rev.	10 21·64
	12·73
	·15
Correction for Flexure, and Errors of Division	1·01
Circle Reading at Observation	31 26 57·49
Zenith Point Correction	7 46·44
Apparent Zenith Distance South	31 34 43·93
Refraction (from below)	36·70
True Zenith Distance South	31 35 20·63
Colatitude	38 31 21·80
OBSERVED NORTH POLAR DISTANCE	70 6 42·43
Star's Correction with Sign Changed	−12·74
MEAN N.P.D. JAN. 1, 1864	70 6 29·65

From Appendix to Gr. Obs. for 1853.	Barometer and B (Table 1) $29^{\text{in}}\cdot97$	·03245
	Thermometer and T (Table 2) $37^{\circ}\cdot8$	·05219
	Z (Table 3)	1·47869
	Proportional Parts	113
		21
	Log. Refraction	1·56467
	Refraction	36·70

The Zenith Point correction is determined from observations of the direct and reflected images of the horizontal wire, combined with those of the direct and reflected images of stars made at the same transit.

803. **Dissemination of Greenwich mean time from the Royal Observatory, Greenwich.**—We have exhibited, in paragraph 801, the use of electro-magnetism as an active agent in the internal daily economy of the Royal Observatory; in the present we will endeavour to show how it is also used for the constant dissemination of true time throughout all parts of the

kingdom. This sending of time signals has become of considerable importance, now that Greenwich time is almost everywhere adopted. The parent, or normal, clock which performs the whole of this daily operation, is a galvanic clock of Shepherd's construction, and was erected in the year 1852. In connection with it there are six others acting in sympathy. The pendulum of the normal clock determines the time at which galvanic currents shall circulate throughout the whole system; thus all the clocks advance together, beat for beat, and all depend on the one pendulum of the normal clock. One of the sympathetic clocks is placed in the external wall of the Observatory, another in the chronometer room, two in the computing room, one in the Astronomer Royal's dwelling-house, and one in the Royal Hospital school the wires to which pass under the ground of Greenwich Park. The normal clock also sends galvanic currents at every second of time, for the purpose of regulating a clock at London Bridge railway station, as well as others in London, on the principle patented by Mr. R. L. Jones. Every morning, it is the duty of the superintendent of the time department to see that the normal clock indicates Greenwich mean time exactly, for which purpose he makes use of the latest available observations made with the transit-circle (47). As the whole system depends on the parent clock, acceleration or retardation of its pendulum accelerates or retards simultaneously all the sympathetic clocks. This delicate operation is performed by the assistant in the most simple manner. A bar magnet is fixed, vertically, on the clock pendulum; underneath a fixed galvanic coil is placed. If we wish to accelerate the pendulum, a current is allowed to flow through the coil, such as shall attract the magnet; when the pendulum is sufficiently accelerated, the current is intercepted. By employing an opposite current to repel the magnet, the clock is retarded. The correction to be made daily is generally very small, and is the work of only a few minutes. The normal clock, which now shows true Greenwich time, is ready to perform its part in sending forth its indications throughout the length and breadth of the land. The following is the process: A galvanic circuit is closed automatically by the clock at the commencement of each hour exactly, causing currents to pass by one wire to London Bridge railway station, and by another wire to the principal office of the Electric and International Telegraph Company in London. The currents received at London Bridge are distributed by Mr. Walker to stations on the South Eastern lines of railway; for which purpose, the clock already mentioned switches the necessary wires into connection with the Greenwich wire, so that the Greenwich signal may pass on uninterruptedly. The currents received by the Electric and International Telegraph Company are distributed by

them in London and the country. Their most important distribution of time is made every day, at 10 A.M., by means of an elaborate apparatus designed by Mr. C. F. Varley. A few seconds before that hour, a large number of wires are switched out of connection with their respective speaking instruments, and into connection with certain relays on which the Greenwich current acts. When this current arrives, relay currents pass out simultaneously on all the wires then in connection, signals being received as far as Brighton in the south, Lowestoft in the east, Cardiff in the west, and Glasgow in the north, including the large towns of Manchester, Birmingham, Liverpool, &c. At one o'clock precisely, the current from the normal clock discharges the Greenwich time-ball; at the same time, the current to London Bridge passes by one of the South Eastern Railway wires to Deal, where a time-ball, belonging to the Admiralty, is discharged for the benefit of the shipping in the Downs. The one o'clock current to the Electric and International Telegraph Company drops their time-ball at Charing Cross, and by relay, fires time-guns, one at Newcastle, and another at Shields. Galvanic currents are sent every hour to the General Post Office, and several of their clocks report automatically their condition to the Observatory. Hourly currents are also sent to the Great Westminster Clock, for the guidance of the attendant. This standard clock of London also reports daily to Greenwich. It is not allowed to deviate more than two seconds from Greenwich time, and usually its error is much less.

The system of distributing hourly time-signals from the Royal Observatory was commenced in the year 1852. The charge of this department of the Observatory has been intrusted, by the Astronomer Royal, to Mr. Ellis, whose published lecture in the seventh volume of the *Horological Journal* contains a full explanation, with diagrams, of every instrument and process used in the dissemination of these time-signals.

804. **Difference of terrestrial longitudes.**—The exact form and dimensions of the earth have been an important subject of research by some of our principal astronomers, particularly MM. Bessel, W. Struve, and Airy. The great Russian arc of parallel, projected by W. Struve, is intended to extend from the Oural river in eastern Europe to the island of Valencia, Ireland. This great geodetical achievement is now nearly concluded, and will remain as a lasting monument to the skill and energy of that illustrious astronomer.

To obtain the measure of the earth from an operation of this kind, it is necessary to refer the length of the arc to some lineal measure, as an English yard, and also to obtain the difference of local times of the two terminal stations. In England, the tri-

angulation of the country between Greenwich and the island of Valencia has been completed many years, and the intermediate country between Greenwich and the Oural river is nearly so; the actual distance between the two distant stations, Valencia and Orsk, will therefore soon be known within very small limits. For the determination of the difference of longitude between two places, many processes have been employed (120 *et seq.*). That, however, which has been lately adopted is by the transmission of galvanic signals, the local time of each being observed at the two stations, in a similar manner to that briefly described in 122. In determining the difference of longitude between Orsk and Valencia, it was found necessary, on account of the great length of the arc, to subdivide it into sections; for instance, separate determinations of longitude were made between Valencia and Greenwich, Greenwich and Nieuport, Nieuport and Bonn, and in like manner between the other stations. At each place, temporary observatories were erected for the convenience of the staff while observing the galvanic signals and the necessary transits of stars for clock-error.

As an illustration of the extreme accuracy with which these operations are performed, we need only refer to two determinations of the longitude of Valencia, made under the direction of the Astronomer Royal. The first was obtained in 1844 by the repeated transmission of a large number of chronometers, by railway and car, from Greenwich to Valencia. By this means, the longitude of the station on the hill Geokaun was found to be $41^{m}23^{s}\cdot23$. In the summer of 1862, the operation was repeated, but this time by the transmission of galvanic signals through the ordinary telegraph wires. On this occasion, the observatory was stationed at the village of Knightstown, on the eastern corner of the island. The resulting longitude is $41^{m}9^{s}\cdot81$. The two stations were afterwards geodetically connected by Capt. A. R. Clarke, R.E., the interval of longitude being $13^{s}\cdot56$, which will make the longitude of the station on the hill Geokaun $41^{m}23^{s}\cdot37$. This agreement is very satisfactory, and gives confidence to both determinations.

The success of the submersion of the Atlantic cable in the summer of 1866, has enabled the astronomer to determine accurately the difference of longitude between Valencia and Heart's Content, Newfoundland. In October and November, 1866, this important work was accomplished under the direction of Dr. Gould, of Cambridge, U.S. This opportunity was taken for determining the longitude of the station of the Atlantic telegraph cable at Foilhommerum bay. The observations were made in the usual manner by transmitting galvanic signals to and from the two stations. The difference of longitude between the two ends of the Atlantic cable has been found to be $2^{h}51^{m}56^{s}\cdot5$, and that between

Greenwich and Foilhommerum, $41^m 33^s{\cdot}29$. The longitude of the latter station, indirectly deduced from the determination made in 1844, is $41^m 33^s{\cdot}24$, and from that in 1862, $41^m 33^s{\cdot}38$.

805. **The Royal Observatory and the Atlantic cable.**—It is not out of place to record here the intimate connection of the astronomical observers at Greenwich with the success of the Atlantic submarine telegraph. This, at first sight, appears strange, but it is no less true that the results of their nightly observations were statedly forwarded to that active group of individuals assembled on board the Great Eastern steamship. One of the most important duties performed during the progress of submerging the cable, was the daily determination, by astronomical observations, of the exact position of the ship, measured by the co-ordinates of latitude and longitude. Now, to obtain the latter, the best astronomical observations would be of little avail, unless true Greenwich mean solar time was known on board. This, in ordinary cases, is obtained by means of one or more chronometers, the errors of which are determined with considerable accuracy before leaving England, by comparison with some normal clock kept to time by the observations of transits of stars in a fixed observatory. As each chronometer has its own peculiar gaining or losing daily rate, true Greenwich time is found from day to day by the application of this rate, until an opportunity arises for a fresh comparison with some observatory clock. In ships where several chronometers are employed, the mean result is sufficiently accurate for ordinary purposes of seamanship. During the time of laying the Atlantic cable, however, it was necessary to know the exact position of the ship with more than ordinary precision. Hence the knowledge of true Greenwich time became a matter of necessity. Arrangements were therefore made by the Astronomer Royal and the Telegraph companies for the transmission of daily signals, at frequent intervals, from the Royal Observatory. In paragraph 803 we have given a brief and general account of the dissemination of the Greenwich time-signals over Great Britain. On this occasion, the signals were sent to Foilhommerum, Valencia, through the ordinary telegraphic wire, and then passed through the whole of the cable, and through the coils of a delicate galvanometer attached to the opposite end. On this instrument the signals were observed almost instantaneously after leaving Greenwich. It can thus be seen that from the time of departure of the Great Eastern from the western coast of Ireland to her arrival at Heart's Content, Newfoundland, the authorities on board were always in possession of Greenwich mean solar time, determined from observations made on the preceding evening with the transit-circle of the Royal Observatory.

806. **Geodetical measurement of the Earth.**—The numbers contained in the following table are frequently useful in astronomical investigations.

Geographical Latitude.	Earth's Radius, Equatorial = 1.	Degree of Meridian in English Feet.	Degree of Parallel in English Feet.
0° 0′	1·00000	362748·33	365185·71
5 0	0·99995	362775·91	363805·29
10 0	0·99990	362857·86	359673·92
15 0	0·99978	362991·74	352821·19
20 0	0·99961	363173·57	343296·36
25 0	0·99941	363397·93	331168·10
30 0	0·99917	363658·14	316524·29
32 30	0·99904	363799·29	308291·66
35 0	0·99891	363946·40	299471·60
37 30	0·99877	364098·36	290080·28
40 0	0·99863	364254·04	280135·01
42 30	0·99848	364412·24	269654·19
45 0	0·99834	364571·77	258657·25
47 30	0·99819	364731·42	247164·66
50 0	0·99805	364889·96	235197·90
51 30	0·99796	364984·06	227799·54
52 30	0·99790	365046·20	222779·41
55 0	0·99776	365198·93	209932·55
57 30	0·99763	365346·99	196681·57
60 0	0·99750	365489·23	183051·59
65 0	0·99726	365751·94	154758·95
70 0	0·99705	365978·97	125270·57
75 0	0·99688	366163·30	94812·70
80 0	0·99676	366299·21	63620·07
85 0	0·99668	366382·49	31933·97
90 0	0·99666	366410·54	00000·00

In the preceding table, the length of a degree of an arc of meridian and of parallel has been converted into English feet from the numbers published in the *Berliner Jahrbuch* for 1852, where the length is given in toises.

807. **New determination of the Sun's equatorial horizontal parallax.**—The uncertainty which had been thrown on the received value of the solar parallax (8″·5776), determined by M. Encke from the transit of Venus in 1769 (546), principally on account of the great suspicion attached to the observations of Father Hell, at Wardhoe, has now been amply confirmed by later investigations. The attention of astronomers was first drawn to this subject in the year 1854, in a letter of M. Hansen, of Götha, addressed to the Astronomer Royal. M. Hansen found, while investigating the lunar theory in connection with the formation of his new tables of the moon, that the parallactic equation exceeded the amount which had hitherto been assigned to it, and consequently indicated a greater value of the solar parallax than that generally adopted. M. Le Verrier, in his researches on the motion of the earth about the sun, deduced 8″·95 as a quantity necessary to satisfy the observations. He was also unable to reconcile the observed places of Venus and Mars with theory without making a similar increase in the parallax. Now, the accurate determination of the coefficient of solar parallax, and with it the distance in miles of the sun from the earth, has always been a problem which astronomers and mathematicians have considered one of the noblest of the science. For upon this knowledge of the sun's distance depends every measure in astronomy beyond the moon; the distance and dimensions of the planets; and also the distances of the fixed stars, or, at least, of those whose parallaxes have been determined.

All our principal astronomers have agreed that the observations of the transit of Venus across the solar disk, are the best means of determining this important problem, and, under ordinary circumstances, we might have been contented to wait for the approaching transits of 1874 and 1882, before attempting to revise the value found from M. Encke's researches. The advancement of theoretical astronomy, however, has been so great during the present century, chiefly by the use of the lunar and planetary observations of Greenwich, that more than one astronomer, as stated above, has been able to announce decidedly the necessity of considerably increasing the hitherto adopted value of the sun's parallax. In 1857, the Astronomer Royal, who has always taken great interest in this problem, and who has already drawn up some preliminary suggestions for the observation of the transit of Venus in 1874 and 1882, recommended a redetermination of the value indirectly from observations on the planet Mars. The distance of Mars from the earth in 1860 and 1862 was about its nearest point, and this circumstance was, therefore, particularly favourable for the determination of its parallax. By concert, a series of meridional zenith distances of Mars and neighbouring stars was consequently observed

at several places in both hemispheres, a list of comparison stars having been specially prepared by Dr. Winnecke. These stars, with the planet, were systematically observed at Greenwich, Pulkowa, Washington, Cape of Good Hope, Williamstown in Australia, and at Santiago.

Another method proposed by the Astronomer Royal, and considered by him to be superior to the observation of meridional zenith distances, was the equatorial observation, at any single observatory, of the displacement of Mars in right ascension when considerably east and west of the meridian. Owing to unfavourable weather at Greenwich, and also on account of the position of Mars in the heavens, the observations by this method were comparatively unsuccessful.

The horizontal solar parallax resulting from the meridional observations of Mars and neighbouring stars, has been determined independently by Dr. Winnecke, of Pulkowa,* and by Mr. Stone, of Greenwich.† Dr. Winnecke employed the observations made at Pulkowa and the Cape of Good Hope, while Mr. Stone used those made at Greenwich, the Cape of Good Hope and Williamstown. The following are what we may consider the modern values from which the newly adopted sun's horizontal parallax has been obtained.

Hansen (Moon's Parallactic Equation) . .	8″·916
Le Verrier (Solar Tables)	8 ·950
Winnecke (Opposition of Mars, 1862) . .	8 ·964
Stone (Opposition of Mars, 1862) . . .	8 ·943

From a combination of the Washington and Santiago observations, the late Captain Gilliss also obtained a value considerably in excess of that of Encke.

The preceding evidence having been considered sufficiently conclusive as to the necessity of a considerable increase to the former adopted value, 8″·5776, Mr. Airy and M. Le Verrier definitely fixed upon 8″·94 as the most probable angular value of the earth's semi-diameter as viewed from the sun. In all celestial distances in miles given in this volume, we have used this value as the basis of our calculation.

The diminution in the sun's distance from the earth of nearly four millions of miles, may, at first sight, appear to some as a flaw in astronomical science. Such, however, is not the fact, if we consider how minute the correction is on which the above change depends. In the words of the Council of the Royal Astronomical Society, we may say that "this correction, amounting to

* *Astronomische Nachrichten*, No. 1409.

† *Memoirs of the Royal Astronomical Society*, vol. xxxiii.

no more than two-fifths of a second of arc, thus curiously brought to light in the first instance by small disturbances in the motion of the moon and planets, may reasonably inspire astronomers with additional confidence (if that were needed) in the exactness of their science, and in the fixedness of the laws which bind the cosmos together. And if, on the other hand, a contrary misgiving is created in other minds from the fact that this abrupt alteration of so important an element as the solar parallax implies an alteration of some four millions of miles in the sun's reputed distance from our earth, this misgiving may perhaps be removed by the consideration that, after all, this improvement of our knowledge amounts to no more than a correction to an observed angle represented by the apparent breadth of a human hair viewed at a distance of about 125 feet."

808. **Telescopic appearance of the solar surface.**—The conjectures occasionally put forth in elucidation of solar physics, have caused great attention to be given of late years to the appearance of the solar disk. First and foremost amongst the workers in this branch of astronomy, the name of Mr. Carrington comes to our mind, as the author of a valuable series of solar observations carried on with the most perfect regularity. At page 165 *et seq.* of this volume, we have briefly explained the generally received theory of the cause of solar spots, and have also shown that their number in different years is both variable and irregular, the solar surface being sometimes completely divested of them, while at other times the spots are spread over in certain parts in great profusion. We have also stated that they are invariably confined to two moderately broad zones parallel to the solar equator, the two zones being separated by a space several degrees in breadth. Glancing at the numerous illustrations in Mr. Carrington's volume, the reader is at once struck with the pictorial confirmation of this phenomenon being generally confined to limited portions of the sun's disk. Mr. Carrington has investigated the possibility of the varying number of solar spots being connected with the influence of the planet Jupiter, whose changing distance might, in some measure, determine their numbers. He has also continued his observations through a whole period of the maximum and minimum frequency of the spots, which he discussed with the object of discovering any laws to which they may be subject. Mr. De La Rue, assisted by MM. Stewart and Loewy, has also devoted much time to the registration and observation of solar spots. The following are a few of the conclusions to which these observers have arrived. "1. The umbra of a spot is nearer the sun's centre than its penumbra, or, in other words, it is at a lower level. 2. Solar faculæ,

and probably also the whole photosphere, consist of solid or liquid bodies of greater or less magnitude, either slowly sinking or suspended *in æquilibrio* in a gaseous medium. 3. A spot including both umbra and penumbra is a phenomenon which takes place beneath the level of the photosphere."* We do not doubt that, by the continuous systematic observations and researches of these astronomers, most important additions will be made to our knowledge of the physical composition of the surface of the sun.

809. **Nasmyth's willow-leaves.**—That every portion of the solar disk should be covered by innumerable bright particles of definite form, of a few seconds of space in length, and a fraction of a second in breadth, is a revelation which the most acute observer of solar phenomena had never dreamt of. We are indebted to Mr. Nasmyth for this important discovery. From his observations we gather, that it appeared to him that these particles had no definite or symmetrical arrangement in the manner in which they were scattered over the sun; on the contrary, they seemed to lie across each other in every possible direction. Mr. Nasmyth observes: "These filaments appear well defined at the edges of the luminous surface when it overhangs the penumbra, as also in the details of the penumbra itself, and most especially are they seen clearly defined in the details of 'the bridges,' as I term those bright streaks which are so frequently seen stretching across from side to side over the dark part of the spot."

This remarkable observation of Mr. Nasmyth has been confirmed by several of our principal astronomers who have the command of powerful instruments. There are, however, some observers of high reputation who have not yet been able to detect these minute solar particles, and who are inclined to consider them to be simply the irregularities which give that granular appearance to the surface of the sun, which has been generally observed for many years past, even with moderately-sized telescopes. For ourselves, we have seen these bright particles with the great equatorial of the Royal Observatory, with a definition so clear, that no doubt remains on our mind of the accuracy of this remarkable discovery of Mr. Nasmyth.

From the similarity in form of these bright solar particles to leaves of the willow-tree, Mr. Nasmyth has distinguished them by the name of willow-leaves. Mr. Stone, who has observed them with the Greenwich great equatorial, has likened them to rice-grains. Different observers have suggested other names as being more appropriate; but it is the opinion of astronomers in general,

* *Researches on Solar Physics*, by Warren De La Rue, Balfour Stewart, and Benjamin Loewy. First series.

that these extraordinary particles of the solar photosphere ought henceforth to be identified solely by the name given by the discoverer; a name in reality sufficiently accurate, although to some eyes the form of a willow-leaf does not represent literally the appearance of these solar fragments.

Among other observers who have devoted particular attention to solar phenomena, we may mention the names of the Rev. F. Howlett, Dr. Selwyn, Professor Phillips, M. Chacornac, and M. Faye, some of whom have deduced very interesting conclusions; for instance, M. Chacornac has published some valuable remarks in the *Comptes Rendus* relative to the variable luminosity and reflective power of various portions of the solar photosphere, and to the successive envelopes which are supposed to enclose the centre of our system.

810. **New chart of the Moon.**—The importance of an accurate delineation of the lunar surface, on a large scale, has been acknowledged for some time, particularly as many omissions have been found in the chart of Beer and Mädler. A new one is therefore in course of construction, under the general superintendence of a committee of the British Association, the actual work being under the special charge of Mr. W. R. Birt. Mr. Birt is availing himself of the labours of previous selenographers, especially Lohrmann, Beer and Mädler, and also of an excellent photograph taken by Mr. De La Rue immediately after the lunar eclipse of the 4th October, 1865. Every object on the lunar surface will, in all probability, find a place in this new chart, the scale of which is 100 inches to the moon's diameter. When completed, this gigantic map will afford to the student of lunar phenomena the best means of acquiring a knowledge of the physical aspect of the moon's surface.

811. **Irregular proper motion of Sirius and Procyon.**—Some very interesting papers on the proper motion of Sirius and Procyon have been communicated to the Royal Astronomical Society, by Messrs. Auwers, Main, Safford, and O. Struve. The apparent variability of the proper motion of these stars had, for some time, attracted the attention of the practical astronomer. With respect to Sirius, M. Calendrelli, of Rome, asserted in 1857, that this variability arose from errors in the composition of the Greenwich catalogues of stars, and not from any peculiar motion of the star itself. Mr. Main has, however, clearly shown that M. Calendrelli was himself in error, and he has also proved that the apparent discordances in question had not their origin in any error of observation or reduction; "but that it depended upon a real fluctuation, most important and interesting, which will render

the motion of this star a serious subject for study during the remainder of the present century." We are indebted to MM. Auwers and Safford for complete investigations of the supposed orbit of Sirius, on the assumption that the irregularities in the proper motion are produced by the perturbations of a dark disturbing body. Some excitement was therefore made by the announcement of the discovery of a companion to Sirius, on the 31st of January, 1862, by Mr. Alvan Clark, of Boston, U. S. The angular position and distance of the companion with respect to Sirius, as observed by M. Otto Struve, are as follows:—

Year.	Position.	Distance.
	°	″
1863·21	82·50	10·15
1864·22	76·50	10·92
1865·20	77·15	10·60
1866·21	75·15	10·93

The researches of M. Auwers on the orbital motion of Sirius require, in three years, an increase of the distance of the disturbing body of $0''\cdot55$, and a diminution of the position angle of $5^{\circ}\cdot31$. These numbers agree so closely with those deduced by M. Struve from his micrometrical measures, that it can scarcely be doubted that the small object discovered by Mr. Alvan Clark is really the cause of the irregularities in the proper motion of Sirius. The magnitude of this companion is excessively minute, commonly it is recorded as the ninth or tenth, so that only on the most favourable occasions, and then with first-class telescopes, is there any possibility of its being seen.

Mr. Newcomb, of Washington, has also discussed the position observations of the companion to Sirius, and has come to the conclusion that this optically minute object is truly a satellite of that brilliant star. He is also of opinion that the observed irregularities in the proper motion of Sirius, are caused by the perturbing influence of this satellite on its primary.

812. **Movement of the solar system in space.**—On page 416, we have given a brief abstract of the investigations on this subject by different astronomers, and we have shown the remarkable agreement existing between the results, with respect to the position of the apex of solar motion. From this we might infer, that its velocity and direction are as accurately known as any other of the celestial movements. But this is not the case, for it must be borne in mind that many of the proper motions by which the results are obtained, are not altogether certain, and that the problem itself has still some speculation mixed up with it. However, this agreement between the independent determinations of

different astronomers, in relation to the point in the heavens to which the direction of solar motion is assigned, has been generally accepted as sufficient evidence for the settlement of the position of this point within a reasonable limit. Most astronomers have followed similar methods of investigation, until Mr. Airy, in 1859, devised a new plan of computation, from a conviction of the inadequacy and defects of the methods hitherto in use.* It is out of place here to enter into any detailed account of this new method of Mr. Airy, because we could scarcely do so without giving all the mathematical formulæ. The general principle of the method, however, consists merely in removing the primary geometrical notions from the apparent movements on the surface of a globe to the real movements of the bodies in space. This is performed by treating the linear movements of the sun and of each star by the use of rectangular co-ordinates. The advantages resulting from the adoption of this method are: 1. That it is perfectly complete and independent, requiring no assumption of a point determined by preceding investigations. 2. It gives the proper weight to each observation, subject to the consideration as to the general weight-multiplier to be attached to any class of stars defined by brilliancy or other characteristic, which may enable us to judge of their distance. Mr. Airy first applied this method to 113 stars whose proper motions are large, arranging them into groups according to magnitude, in conformity with the researches of W. Struve, whose assumed relative distances were also adopted. From the most probable of two assumptions, Mr. Airy found the right ascension of the apex of solar motion to be 261° 29′, the north polar distance 65°16′, and the velocity of solar motion 1″·912. This large velocity depends principally on the excessive proper motions of a few of the stars. In undertaking this preliminary investigation, Mr. Airy expressed a wish that it should be considered only as a specimen of the application of a new method, which he hoped would be applied to a larger number of stars.

The continuation of this investigation was at once commenced at the Royal Observatory, and in 1863, a second paper was prepared by Mr. Dunkin, at the request of the Astronomer Royal.† On this occasion, the proper motions of 1,167 stars were employed, 819 of which are situate in the northern, and 348 in the southern hemisphere. As in the former paper, the investigation was made on two hypotheses:—first, by supposing that the irregularities of proper motion are entirely due to chance-error of observation; and second, that they are due solely to a peculiar motion

* *Memoirs of the Royal Astronomical Society*, vol. xxviii.
† *Ibid.* vol. xxxii.

of the stars themselves. From the first of these hypotheses, the following results have been obtained:—

R. A. of solar apex $= 261^\circ\ 14'$
N. P. D. " " $= 57\ \ 5$
Annual velocity of solar motion $= 0''\cdot3346$.

The results on the second and more probable hypothesis are as follows:—

R. A. of solar apex $= 263^\circ\ 44'$
N. P. D. " " $= 65\ \ 0$
Annual velocity of solar motion $= 0''\cdot4103$.

It will be observed, from the preceding numbers, that the annual velocity of solar motion, or the angular displacement of the sun as viewed from a star of the first magnitude, differs but slightly from that determined from the researches of M. Otto Struve ($0''\cdot3392$). The mean of the three values gives $0''\cdot3614$. Now, if we assume this to be the probable amount of the proper motion of the solar system in space, and that the average parallax of a star of the first magnitude is $0''\cdot209$, we shall find, by comparing the annual solar motion with the radius of the earth's orbit, that it amounts to 1·729 of such units, or, in round numbers, 158 millions of miles.

Thus far it will be seen that the direction of solar motion given by these two investigations agrees generally with that found by former astronomers, and therefore, *primâ facie*, the result may be considered satisfactory. If, then, these proper motions depend in a great measure on a proper motion of the sun, we might expect to find that if we take the sums of the squares of the residua uncorrected for solar motion, and again when corrected, the sums of the latter would be considerably diminished. The following is the result of this comparison:—

Sum of squares of Motion in Parallel $\begin{cases} \text{Uncorrected} = 78''\cdot7583 \\ \text{Corrected} = 75\ \cdot5831 \end{cases}$

Sum of squares of Motion in N. P. D. $\begin{cases} \text{Uncorrected} = 63\ \cdot2668 \\ \text{Corrected} = 60\ \cdot9084 \end{cases}$

The small diminution in the corrected numbers is very curious, and it shows that our fundamental suppositions must rest, to some extent, on a slender basis; and the results, notwithstanding the general agreement in the position of the solar apex, warrant the question whether we have much ground to infer that the proper motions of the stars are produced principally by the motion of the sun and its system in space. It may be, and probably such an inference is partially true, that these apparent motions in the positions of the stars are rather due to some compound effect, resulting from causes some of which have yet to be discovered. Again, we may remark that the grounds upon which we have been working

are uncertain to a considerable extent, which uncertainty will scarcely be removed until our knowledge of the distances of the stars is increased, or until the proper motions themselves are re-determined from unexceptionable observations made at both epochs with the improved instruments of modern times.

Referring to the small diminution in the sums of the squares in Mr. Dunkin's corrected numbers, Sir John Herschel observes: "No one need be surprised at *this*. If the sun move in space, why not also the stars? and if so, it would be manifestly absurd to expect that any movement could be assigned to the sun by any system of calculation which should account for more than a very small portion of the totality of the observed displacements. But what is indeed astonishing in the whole affair, is, that among all this chaotic heap of miscellaneous movement, among all this drift of cosmical atoms, of the laws of whose motions we know absolutely nothing, it should be possible to place the finger on one small position of the sum total, to all appearance undistinguishably mixed up with the rest, and to declare with full assurance that this particular portion of the whole is due to the proper motion of our own system." *

813. **Observations of the spectra of stars and nebulæ.**—Some very important observations of the spectra of the fixed stars and nebulæ have been made during the last few years, in this country, principally by Mr. Huggins and Dr. W. A. Miller. A series of observations has also been made at the Royal Observatory, by Mr. Carpenter, in which the dark lines of the stellar spectra have been micrometrically measured in reference to the principal fixed lines of the solar spectrum.† In comparing the lines of the stellar spectra with those of certain chemical elements, Mr. Huggins and Dr. Miller have found several remarkable coincidences occur. For example, in the spectrum of Aldebaran, coincidences with nine of the elementary bodies were observed, viz. sodium, magnesium, hydrogen, calcium, iron, bismuth, tellurium, antimony, and mercury. In Sirius and α Orionis, five cases of coincidence were found. These comparisons have been made on a number of other stars, in some of which corresponding lines have been observed, whereas in other cases no lines coincident with those of any known chemical element have been noticed.

Mr. Huggins has also analysed the light of several nebulæ and clusters. These objects give either a continuous spectrum, analogous

* *Outlines of Astronomy*, eighth edition, p. 704.

† For an explanation of the spectroscope and of the method of observing Fraunhofer's lines of the solar spectrum, the reader is referred to Lardner's *Handbook of Natural Philosophy.—Optics*, p. 145.

to the spectra of the sun and stars, or a spectrum consisting of one, two, or three bright lines, indicating the gaseous nature of their composition. It has been found that when the light of a nebula is dispersed by the prism, the continuous spectrum is very faint, its light being of all refrangibilities. In consequence of this, observers have not yet been able to discover whether it is crossed by dark lines or not. Mr. Huggins' paper contains a list of six of the small planetary nebulæ, in which the spectrum of three bright lines is visible. The Dumb-bell nebula (733, Plate XXX., *fig.* 3), and one in Lyra give a similar spectrum. Mr. Huggins observes that, "since the light from these nebulæ emanates from a gaseous source, we have an explanation of the small intensity of their light; and, it may be, also to some extent of the strange appearances which some of them present, for on account of the absorption by the portions of gas nearest to us of the light from the gas behind them, there would be presented to us little more than a luminous surface." The great nebula in Orion (736) also belongs to this class of gaseous bodies, as shown by its spectrum of three bright lines.

With respect to the probable relation of the gaseous nebulæ to the other nebulæ and clusters, Mr. Huggins considers that a more intense heat may be indicated by the superior intensity of the light of the gaseous nebulæ. It is possible, therefore, that of all the objects usually included among the nebulæ, those which give a gaseous spectrum are, as a class, to be considered as generating more heat than those giving a continuous spectrum.

Since the celebrated researches of MM. Kirchhoff and Bunsen on the coincidences of the dark lines of the solar spectrum with those of certain chemical elements, no foreign astronomer has devoted more consideration to spectrum analysis than M. Secchi of Rome. From his observations, we gather that the spectrum of α Herculis presents to the eye an appearance of a series of fluted columns. The striking contrast between the luminous and the dark portions produces a remarkable stereoscopic effect. The columns are again resolved into finer lines. One line coincides with Fraunhofer's line D of the solar spectrum; two others, one of which is larger and double, with the magnesium line. The spectrum of ρ Persei resembles that of α Herculis. M. Secchi has formed the following conclusions as the result of his investigations so far. 1. The type of the white, or bluish stars, like Sirius and α Lyræ, is marked by a broad band near the place of the line F, and another at the beginning of the violet end of the spectrum. Occasionally a third band, with very fine lines, is visible in the spectra of the brightest stars of this type near the extreme end of the violet. 2. Spectra with large bands, as in α Orionis, Antares,

&c., and stars generally of a red or orange tint; these are often confounded with the next class. Aldebaran comes between the two classes. 3. The type of our sun, comprising Capella, Arcturus, Pollux, &c. Their spectra is covered with fine lines, and direct measurement has shown that they occupy the place of the principal lines of the solar spectrum. An accessory type is that of the constellation Orion, in which all the stars have very similar spectra, characterised by a greenish tint, and in which the line F is very thin. M. Secchi remarks that "each type prevails in one region of the heavens; the green in Orion, the yellow in Cetus, the blue in the Pleiades, Ursa Major, Corona Borealis, &c., while the distinct type represented by α Lyræ includes nearly half of the stars which I have submitted to spectrum analysis."

The spectrum of γ Cassiopeiæ, as observed by M. Secchi, exhibits an appearance very different from that of any other star of a similar colour. For example, in the great majority of white stars, the line F is very clear and broad, as in the spectra of α Lyræ, Sirius, &c. Instead, therefore, of this ordinary *dark* line in the spectrum of γ Cassiopeiæ, there is in its place a very fine *luminous* line which is considerably more brilliant than any other portion of the spectrum. By the aid of a micrometer this bright line was found to coincide *exactly* with the position of the line F. It is premature to decide whether this peculiar spectrum is only a type of many others, or whether it is an isolated example of a star with a physical constitution different from that of its neighbours. Further observations will probably settle this point when the light of most of the visible stars has been systematically analysed. At present, however, it is certainly unique in its character, excepting that the luminous line makes this spectrum something analogous to that of the remarkable variable star in Corona Borealis, a brief description of which we have given in the next paragraph (814). There is, however, this difference in the spectra of these two stars, that whereas the bright line in that of γ Cassiopeiæ has only been satisfactorily observed by one astronomer, the peculiar spectrum of the variable in Corona Borealis has been seen and the position of the bright lines measured, with respect to the corresponding dark lines of the solar spectrum, by several observers in different countries.

This new branch of astronomy offers a wide field for reflection, as it tends to increase our knowledge of the original composition of the numerous objects scattered over the heavens. It is, however, yet in its infancy; but we doubt not, that, by the energy of those who have taken up this interesting department of our science, we shall, year by year, add fresh materials to our store, the full advantage of which will be reaped at a future time.

814. **Remarkable spectrum of a star in Corona Borealis.**—This extraordinary object suddenly appeared as a star of the second magnitude, on the 12th of May, 1866, near ϵ Coronæ. Several observers noticed it independently both in Europe and America. Its brightness began to diminish from the day of discovery, decreasing at the average rate of half a magnitude per day. By the second week in June, the star was only of the ninth magnitude. It has been identified with an object observed by M. Argelander, of Bonn, and is catalogued as No. 2765, zone $+26°$, in his *Bonner Sternverzeichniss* as of the $9\frac{1}{2}$ magnitude.

Mr. Huggins was the first to observe the spectrum of this star. He found it of the most remarkable character, unlike that of any celestial body which he had hitherto examined. When viewed with the spectroscope, its light was found to be compound, emanating from two different sources. "Each light forms its own spectrum. In the instrument these spectra appear superposed. The principal spectrum is analogous to the sun, and is evidently formed by the light of an incandescent solid or liquid photosphere, which has suffered absorption by the vapours of an envelope cooler than itself. The second spectrum consists of a few bright lines, which indicate that the light by which it is formed was emitted by matter in the state of luminous gas." *

The double spectrum of this star has been observed at different observatories, confirming completely the observations of Mr. Huggins. Many explanations or speculations have been given as to the origin of this apparently sudden outburst; but before any definite opinion can be settled, we must wait for further observations. Possibly the star may really be one of the class of variables, with a regular, but unknown, period of maximum and minimum brightness. In the autumn of 1866, its magnitude had again increased to between the seventh and eighth. From observations made with the Greenwich transit-circle, its mean place in the heavens for January 1, 1866, is:

R. A.	N. P. D.
h m s	° ′ ″
15 53 53·8	63 41 52·9

815. **Catalogue of Variable Stars.**—The following list of variable, or periodic, stars has been compiled from the most recent observations, more especially, however, from the catalogue published by Dr. Schönfeld, of Mannheim.† It will be at once seen that the table is more complete than that contained in paragraph 687. The right ascensions and north polar distances are given for the epoch 1870.

* *Proceedings of the Royal Society*, vol. xv. No. 84.

† *Catalog von veränderlichen Sternen, mit Einschluss der neuen Sterne.* 1866.

No.	Name of Star.	R.A.	N.P.D.	Variation of Magnitude.	Period.	First Observer of Variability.	Year.
		h. m. s.	° ′	from to	days		
1	R Andromedæ	0 17 12	52 9	6·3 under 12·5	402	Argelander	1858
2	B Cassiopeiæ	0 17 36	26 34	. . . .	. .	Tycho Brahe	1572
3	T Piscium	0 25 16	76 7	9·5 11·0	146·4	R. Luther	1855
4	α Cassiopeiæ	0 33 9	34 11	2·2 2·8	79·5	Birt	1831
5	U Piscium	0 37 35	83 25	9·0? ?	?	Hind	1860
6	S Cassiopeiæ	1 10 8	18 4	8·0 under 13·0	. .	Argelander	1861
7	S Piscium	1 10 46	81 46	8·8 under 12·0	406·2	Hind	1851
8	R Piscium	1 23 56	87 47	7·4 under 12·0	347	Hind	1850
9	V Piscium	1 47 30	81 51	6·5? 8·5?	. .	Argelander	1863
10	S Arietis	1 57 39	78 6	10·0 under 13·0	. .	C. H. F. Peters	1865
11	R Arietis	2 8 44	65 33	7·7 12·5	185·2	Argelander	1857
12	ο Ceti	2 12 46	93 34	1·7 9?	331·34	D. Fabricius	1596
13	ε Persei	2 56 51	51 40	3·4 4·0	33	Schmidt	1854
14	β Persei	2 59 43	49 33	2·3 4·0	2·87	Goodricke	1782
15	R Persei	3 21 47	54 47	8·8 under 12·0	210	Schönfeld	1861
16	λ Tauri	3 53 29	77 53	3·4 4·3	3·95	Baxendell	1848
17	U Tauri	4 14 15	70 30	9·2 under 10·0	. .	Baxendell	1862
18	T Tauri	4 14 25	70 46	9·6 under 12·0	. .	Hind	1852
19	R Tauri	4 21 10	80 8	8·2 under 13·0	326·3	Hind	1849
20	S Tauri	4 22 5	80 21	9·9 under 13·0	378	Oudemans	1855
21	R Orionis	4 51 55	82 4	9·0 under 13·0	378	Hind	1848
22	ι Aurigæ	4 52 38	46 22	3·5 4·5	350?	Heis	1846
23	R Leporis	4 53 41	105 0	6·0 9?	439	Schmidt	1855
24	R Aurigæ	5 6 48	36 34	6·6 12·7	465	Argelander	1862
25	δ Orionis	5 25 22	90 24	2·2? 2·7	. .	J. Herschel	1834
26	α Orionis	5 48 8	82 37	1·0 1·4	196	J. Herschel	1836
27	R Monocerotis	6 32 4	81 9	9·5 under 12·0	. .	Schmidt	1861
28	ζ Geminorum	6 56 24	69 14	3·7 4·5	10·16	Schmidt	1847
29	R Geminorum	6 59 32	67 6	6·8 under 10·5	370	Hind	1848
30	R Canis Minoris	7 1 34	79 46	7·0 under 10·5	339	Argelander	1854
31	S Canis Minoris	7 25 40	81 24	7·2 under 11	336	Hind	1856
32	T Canis Minoris	7 26 46	77 59	9·5? under 13	. .	Argelander	1865
33	S Geminorum	7 35 14	66 15	8·7 under 13	294	Hind	1848
34	T Geminorum	7 41 30	65 57	8·1 under 13	287	Hind	1848
35	U Geminorum	7 47 23	67 39	9·0 13	97·1	Hind	1855
36	R Cancri	8 9 24	77 53	6·3 under 11	353·6	Schwerd	1829
37	U Cancri	8 28 19	70 39	8·2 under 13	306	Chacornac	1853
38	S Cancri	8 36 30	70 30	8·2 10·2	9·48	Hind	1848
39	S Hydræ	8 46 47	86 26	7·5 under 12	256·4	Hind	1848
40	T Cancri	8 49 14	69 39	8·5 11	454	Hind	1850
41	T Hydræ	8 49 20	98 39	7·0 under 12	289·1	Hind	1851
42	α Hydræ	9 21 12	98 6	2·3 2·7	55?	J. Herschel	1837
43	R Leonis Minoris	9 37 46	54 53	7·0 under 11	373	Schönfeld	1863
44	R Leonis	9 40 34	77 58	5·3 10·5	312·09	Koch	1782
45	R Ursæ Majoris	10 35 25	20 33	6·8 12	302	Pogson	1853
46	η Argûs	10 40 1	149 0	1·0 under 6	?	Burchell	1827
47	S Leonis	11 4 7	83 50	9·0 under 13	190	Chacornac	1856
48	T Leonis	11 31 46	85 54	10? under 13	. .	C. H. F. Peters	1862
49	R Comæ	11 57 35	70 30	8·0 under 12	358	Schönfeld	1856
50	T Virginis	12 7 56	95 19	7·9 under 12·5	336	Boguslawski	1849
51	T Ursæ Majoris	12 30 28	29 48	6·5 13	257·3	Argelander	1860
52	R Virginis	12 31 54	82 18	6·5 10·5	145·72	Harding	1809
53	S Ursæ Majoris	12 38 15	28 12	7·6 11	224·8	Pogson	1853
54	U Virginis	12 44 30	83 44	7·5 12·5	207·6	Harding	1813
55	V Virginis	13 21 6	92 30	7·9 under 13	252	Goldschmidt	1858
56	R Hydræ	13 22 37	112 37	4·5 10?	447·85	Maraldi	1704
57	S Virginis	13 26 13	96 32	5·7 under 11	373·6	Hind	1852
58	T Boötis	14 8 0	70 19	9·7? under 13	. .	Baxendell	1860
59	S Boötis	14 18 32	35 36	8·0 under 12·5	271	Argelander	1860
60	R Camelopardi	14 27 35	5 35	7·2 12?	265·7	Hencke	1858

No.	Name of Star.	R.A.	N.P.D.	Variation of Magnitude.		Period.	First Observer of Variability.	Year.
		h. m. s.	° ′	from	to	days		
61	R Boötis - -	14 31 28	62 42	7·2	12·5	222·5	Argelander	1858
62	U Boötis - -	14 34 48	61 59	9·5 ?	12 ?	. .	Baxendell	1864
63	δ Libræ - -	14 54 1	98 0	4·9	6	6·98	Schmidt	1859
64	S Serpentis - -	15 15 34	75 13	7·6	13 ?	362·3	Harding	1828
65	S Coronæ - -	15 16 6	58 10	6·5	12	356	Hencke	1860
66	R Coronæ - -	15 43 13	61 27	6·0	13 ?	350	Pigott	1795
67	R Serpentis -	15 44 44	74 28	5·7 under	11	351·74	Harding	1826
68	R Libræ - -	15 46 15	105 51	9·3 under	13	722	Pogson	1858
69	T Coronæ - -	15 54 4	63 43	2·0	9·5	. .	Birmingham	1866
70	R Herculis - -	16 0 23	71 17	7·8 under	13	317·1	Argelander	1855
71	T Scorpii - -	16 9 18	112 39	7·0 under	10	. .	Auwers	1860
72	R Scorpii - -	16 9 54	112 37	9·0 under	13	648	Chacornac	1853
73	S Scorpii - -	16 9 56	112 35	9·3 under	13	364	Chacornac	1854
74	U Scorpii - -	16 14 59	107 35	9·0 under	13	. .	Pogson	1863
75	U Herculis - -	16 20 3	70 49	7·0	11 ?	413	Hencke	1860
76	30 Herculis - -	16 24 22	47 50	4·9	6·2	106	Baxendell	1857
77	T Ophiuchi - -	16 26 18	105 51	10 ? under	12	. .	Pogson	1860
78	S Ophiuchi - -	16 26 47	106 53	9·1 under	12·5	234	Pogson	1854
79	S Herculis - -	16 45 59	74 50	6·3	12	303	Schönfeld	1856
80	Nova Ophiuchi -	16 52 13	102 41	5·5 under	14	. .	Hind	1848
81	R Ophiuchi - -	17 0 18	105 55	8·0 under	12	304·6	Pogson	1853
82	α Herculis - -	17 8 43	75 28	3·1	3·9	88·5	W. Herschel	1795
83	Nova Serpentarii -	17 22 51	111 22	. .	. .	. .	D. Fabricius	1604
84	T Herculis - -	18 4 11	59 0	7·5	12·3	165·2	Argelander	1857
85	T Serpentis - -	18 22 28	83 47	10·5 under	13	310	Baxendell	1860
86	R Scuti - -	18 40 33	95 51	4·7	6·9	71·7	Pigott	1795
87	β Lyræ - -	18 45 17	56 47	3·5	4·5	12·91	Goodricke	1784
88	R Lyræ - -	18 51 23	46 13	4·3	4·6	46	Baxendell	1856
89	R Aquilæ - -	19 0 7	81 58	6·7 under	11	349·5	Argelander	1856
90	T Sagittarii -	19 8 43	107 11	8·0 under	11	. .	Pogson	1863
91	R Sagittarii -	19 9 4	109 32	7·8 under	12	467	Pogson	1858
92	S Sagittarii -	19 11 49	109 16	10·0 under	12	. .	Pogson	1860
93	R Cygni - -	19 33 20	40 5	6·2	13	425	Pogson	1852
94	11 Vulpeculæ -	19 42 14	63 0	3·0	?	. .	Anthelm	1670
95	S Vulpeculæ -	19 43 4	63 2	8·5	9·5	67·92	Rogerson	1837
96	χ^2 Cygni - -	19 45 34	57 25	4·0 under	11	406·12	Kirch	1686
97	η Aquilæ - -	19 45 51	89 20	3·5	4·7	7·18	Pigott	1784
98	S Cygni - -	20 2 47	32 23	8·8 under	13	323	Argelander	1860
99	R Capricorni -	20 4 1	104 39	9·0 under	13	349	Hind	1848
100	S Aquilæ - -	20 5 39	74 46	8·9	11	122·5	Baxendell	1863
101	R Sagittæ - -	20 8 8	73 40	8·3	10	70·58	Baxendell	1859
102	R Delphini - -	20 8 39	81 19	8·4 under	12·5	. .	Hencke	1851
103	P Cygni - -	20 13 0	52 22	3·0 under	6	18 yrs.	Jansen	1600
104	R Cephei - -	20 23 41	1 16	5 ?	10 ?	73 yrs.	Pogson	1856
105	S Delphini - -	20 37 5	73 23	8·0	11	283dys	Baxendell	186x
106	T Delphini - -	20 39 20	74 4	8·4 under	13	332	Baxendell	1863
107	U Capricorni -	20 40 54	74 44	10·0 under	12	420	Pogson	1858
108	T Cygni - -	20 42 0	56 6	5·0	6·5	. .	Schmidt	1864
109	T Aquarii - -	20 43 6	95 38	7·5	13	205	Goldschmidt	1861
110	R Vulpeculæ -	20 58 36	66 41	8·0	13	138·6	Argelander	1858
111	T Capricorni -	21 14 45	105 39	9·0 under	13	270	Hind	1854
112	S Cephei - -	21 36 47	11 58	8·5	11·5	470	Hencke	1858
113	μ Cephei - -	21 39 31	31 49	4·0	5	419	W. Herschel	1782
114	T Pegasi - -	22 2 33	78 6	9·1 under	12	374	Hind	1863
115	δ Cephei - -	22 24 21	32 15	3·7	4·9	5·37	Goodricke	1784
116	S Aquarii - -	22 50 8	111 2	7·7 under	11	279·35	Argelander	1853
117	β Pegasi - -	22 57 28	62 37	2·2	2·7	41	Schmidt	1848
118	R Pegasi - -	23 0 7	80 9	8·0 under	11	378	Hind	1848
119	R Aquarii - -	23 37 6	106 0	5·8 under	11	388	Harding	1811
120	R Cassiopeiæ -	23 51 49	39 20	5·7 under	12·5	430	Pogson	1853

93. See paragraph 689.

94. A celebrated temporary star. ... magnitude is visible near its place at

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NOTE.—The following elements of ... after Table I. was printed. Their pl... Pomona and Melete.

Mean diurnal motion	.
Sidereal Period .	.
Mean distance from Sun	.
Excentricity .	.
Mean Longitude .	.
Longitude of Perihelion	.
Longitude of Ascending Node	
Inclination . .	.
Mean Solar Time of Epoch	
Authority . .	.

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NOTE.—This Index refers to the numbers of the paragraphs, and not to the pages.

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NAME	DATE DUE